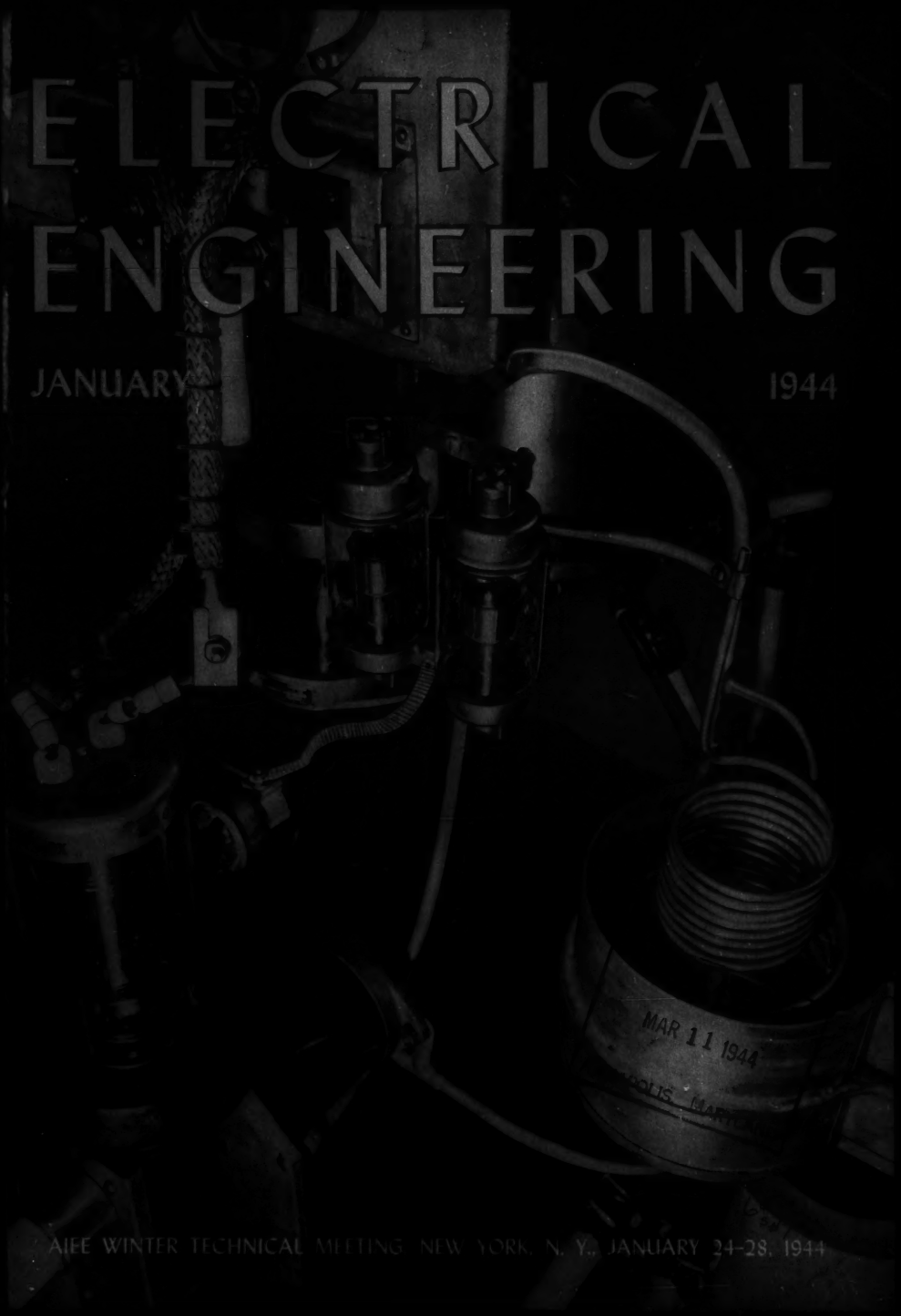
ELECTRICAL ENGINEERING

JANUARY 1944



MAR 11 1944

AIEE WINTER TECHNICAL MEETING, NEW YORK, N. Y., JANUARY 24-28, 1944

PORCELAIN
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Porcelain Dielectric Is The *Essence* of O-B BUSHING DESIGN

O-B bushings are distinguished by one feature--porcelain dielectric. Porcelain cannot be harmed by un-predictable discharges or leakage currents. Porcelain can't be altered by time in the slightest way. Porcelain is broadly conceded to be the most stable, rugged high-voltage insulating material... Porcelain insulation now carries the voltage to your sub-stations. Let it carry that voltage safely the rest of the way--right to the windings of your apparatus... Specify O-B porcelain bushings.

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CANADIAN OHIO BRASS CO., LTD., NIAGARA FALLS, ONT.

Do you have a tough wartime wire problem?

Let Belden Wire Engineering Service help you

Are your engineers or production men battling with a tough winding job? If you want help, ask the Belden Wire Engineering Service to look over your problem. They will gladly offer their recommendations without obligating you in any way.

Belden Wire Engineers are in a position to give valuable advice on winding equipment, dereelers, coil finishing machines, coil impregnation, and baking. Their broad experience also covers the selection of the best type of wire insulation for a particular coil winding job or the determination of correct wire sizes and tolerances to meet unusual specifications. They have developed several interesting and simple tests to check the quality of incoming wire shipments.

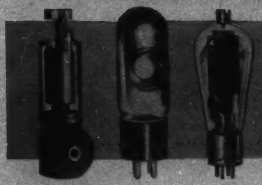
Write for bulletin on Belden Dereeler shown above.

Belden Wire Engineers will gladly check your winding machines and recommend adjustments or changes if you are running into unusual winding difficulties. Many manufacturers avail themselves of this service, when confronted with a tough wartime winding problem.

Belden Manufacturing Co., 4635 W. Van Buren St., Chicago 44

Belden Magnet Wires

ELECTRICAL ENGINEERING. Published monthly by the American Institute of Electrical Engineers; publication office 20th & Northampton Streets, Easton, Pa. Editorial and advertising offices, 33 West 39th Street, New York 18, N. Y. Subscription $12 per year plus extra postage charge to all countries to which the second-class postage rate does not apply; single copy $1.50. Entered as second-class matter at the Post Office, Easton, Pa., under the Act of Congress of March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P.L. & R. Act of February 28, 1925. January 1944, Vol. 63, No. 1. Number of copies of this issue 25,000



A G-E X-ray tube (1), a G-E phototube (2), a G-E thyratron tube (3), and several G-E amplifier tubes are the "eyes and brains" of this ingenious machine.

To safeguard our fighting men, hand grenades must be flawless—*every* fuse must be timed to split-second accuracy.

From the engineering laboratory of General Electric has come an automatic X-ray inspector—the first of its kind—which checks time fuses at the incredible rate of 4000 an hour . . . with the unerring accuracy no other inspection method can even approach.

A movable belt carries the fuses through the penetrating beam of a 100,000-volt G-E X-ray tube which casts its glow on a fluorescent screen. A G-E phototube, or "electric eye," inspects the glow. If constant, verdict is "O.K." If intensity changes, powder charge is inadequate for proper timing. Instantaneously, a four-way alarm is given . . . a bell rings; a red light flashes; the imperfect fuse gets a dab of red paint; a photo-electric meter chart records the "dud."

It is the purpose of G-E electronic tube engineers to aid any *manufacturer* of electronic devices in the application of tubes. Through its nation-wide distribution system, G. E. is also prepared to supply *users* of electronic devices with replacement tubes.

FREE BOOKLET ON ELECTRONIC TUBES

Send us the names of interested men in your plant. We will mail them, without charge, an illustrated, easily understood book on "How Electronic Tubes Work." Address *Electronics Department, General Electric, Schenectady, N.Y.*

• *Tune in "The World Today" and hear the news direct from the men who see it happen, every evening except Sunday at 6:45 E.W.T. over CBS. On Sunday listen to the G-E "All Girl Orchestra" at 10 P.M. E.W.T. over NBC.*

G. E. HAS MADE MORE BASIC ELECTRONIC TUBE DEVELOPMENTS THAN ANY OTHER MANUFACTURER

GENERAL ELECTRIC

182-C 1-8850

GET THESE SAVINGS

- 88% REDUCTION IN COPPER REQUIREMENTS
- 81% REDUCTION IN COPPER LOSSES
- 45% REDUCTION IN COST

PLACE TRANSFORMERS CLOSE TO THE STATION...

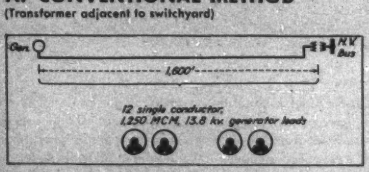
AND INSTALL OILOSTATIC HIGH-VOLTAGE TRANSFORMER LEADS HERE

COMPARE THE RELATIVE MERITS OF THESE TWO METHODS*

LOAD: 70,000 KVA to be carried 1600 feet from generator to switchyard.

A. CONVENTIONAL METHOD

(Transformer adjacent to switchyard)

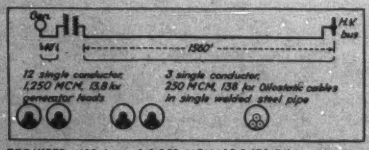


REQUIRED: 19,200 feet of 1,250 MCM, 13.8 KV Oilostatic transmission cable plus risers.

Total Copper — 77,538 Pounds.

B. NEW METHOD

(Transformer adjacent to generating station)


Gen.
M.V.
H.V. Bus
1580'
12 single conductor, 1,250 MCM, 13.8 kv generator leads
3 single conductor, 250 MCM, 138 kv Oilostatic cables in single welded steel pipe

REQUIRED: 480 feet of 1,250 MCM, 13.8 KV Oilostatic transmission cable plus risers.

4680 feet of 250 MCM 138 KV Oilostatic transmission cable plus risers.

Total Copper — 7,562 Pounds.

RESULTS:

1. The new method (B) requires only 9.76% of the copper needed in the conventional method (A).
2. Copper losses in (B) are only 18.75% of those in (A).
3. Cost of the *entire* cable installation in (B) is only 55% of the cost of the conventional method.
4. Improved lightning protection is gained through the capacity of the long length of cable between switchyard and transformer.

* Based on recent study of a proposed installation.

Through Okonite-Callender research the large savings inherent in high-voltage transmission can be more fully obtained by operating and station design engineers who take advantage of the improved layout permitted by Oilostatic high-voltage transformer leads. The only changes from conventional practice are to place transformers closer to the station and install high-voltage Oilostatic transformer leads between the high side of the transformers and the switchyard. Comparable savings are effected regardless of the type of cable used for low-voltage generator leads.

THIS METHOD HAS BEEN PROVED IN THE FIELD

An installation of this design is in operation at one of the largest base load stations in the United States (see Electrical World — Feb. 22, 1941). Moreover, the reliability and trouble-free performance of the Oilostatic high-voltage transmission system itself have been established through more than 11 years' experience in numerous other applications. For transmission circuits, station ties, transformer and generator leads, it will pay you to consider this modern, economical cable transmission system. Write for Bulletins OK-1016 and OK-2028 . . . or talk it over with our engineers. The Okonite-Callender Cable Co., Inc., Passaic, N. J.

3479

OKONITE-CALLENDER

PAPER-INSULATED POWER CABLES

Photographs Courtesy Boeing Aircraft

AFTER DETERMINING the cause of brush failure at high altitude on aircraft equipment, the Research Laboratories of National Carbon Company, Inc., discarded the practice of treating brushes by impregnation and developed a type of brush composition which produces a protective film on the commutator and assures satisfactory commutation and brush life under all service conditions—from take-off to ceiling.

As a result of tests in actual high altitude flights, four grades have been developed with characteristics that cover practically every type of rotating electrical equipment used on aircraft. Although designed primarily for operation at the low temperature, low humidity and rarefied atmospheric conditions of high altitude, these brushes also show highly satisfactory performance under comparatively high temperature and high humidity conditions at sea level.

GRADE AJS — A specially bonded graphite grade for high altitude operation on medium and high voltage commutators of dynamotors, 30-volt motors and other aircraft equipment not subject to excessive temperature conditions. This grade has fairly high contact drop.

GRADE AJZ — A graphite grade containing 25% copper adapted to high altitude operation on aircraft motors, interpole generators and similar applications. The contact drop of this grade is lower than that of Grade AJS.

GRADE AJT — A high altitude metal-graphite grade containing 50% copper and with low contact drop, it gives excellent service on 30-volt aircraft equipment such as motors, amplidynes, inverters, low voltage commutators of dynamotors, interpole generators and slip rings. Used at current densities ranging from 160 to 200 amperes per square inch.

GRADE ALP — A metal-graphite grade with approximately 65% copper and very low contact drop, for low voltage dynamotor commutators on which brush performance is affected by high altitude and because of the need for a grade of still lower contact drop than AJT.

These brushes have been developed for military aircraft. Both now and after the war, the research facilities of National Carbon Company will continue preeminently qualified for solution of brush problems imposed by the unceasing development of all types of rotating electrical equipment.

★ *BUY UNITED STATES WAR BONDS* ★

NATIONAL CARBON COMPANY, INC.
Unit of Union Carbide and Carbon Corporation
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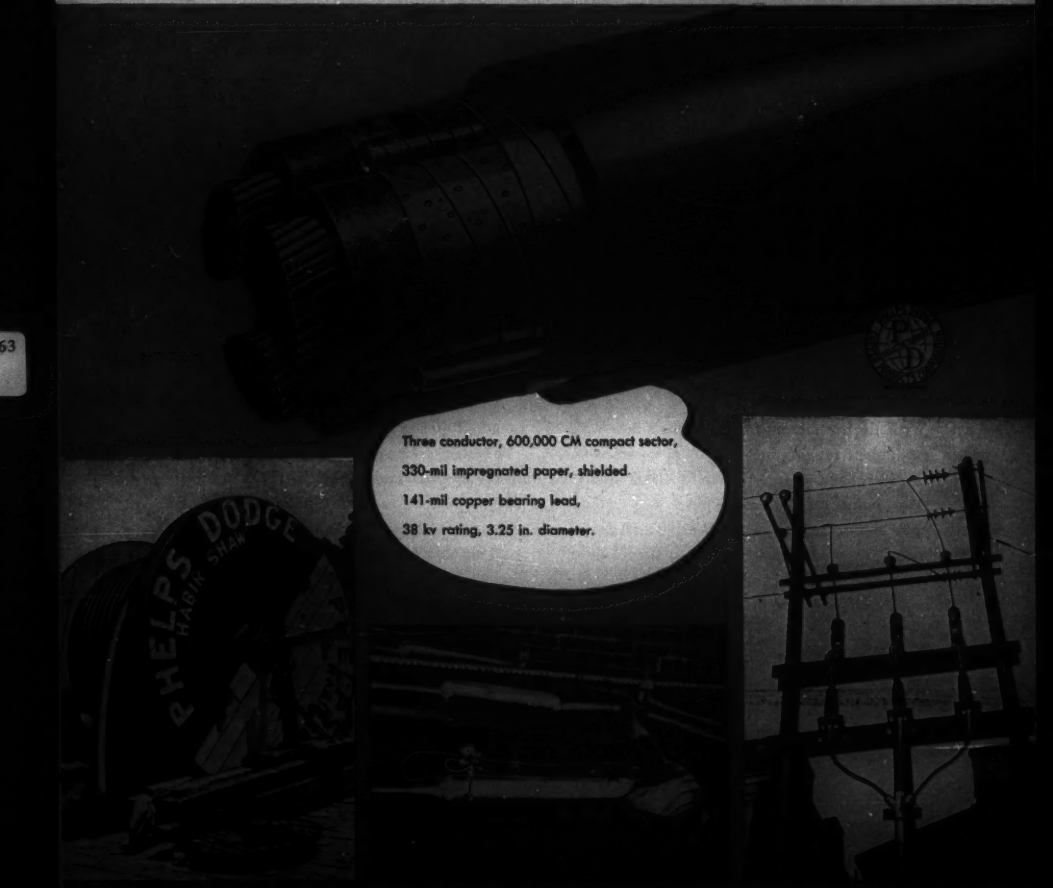
HABIRSHAW
GAS-FILLED CABLE

OPERATING AT 38 KV AT NORFOLK, VA.



Three conductor, 600,000 CM compact sector,
330-mil impregnated paper, shielded
141-mil copper bearing lead,
38 kv rating, 3.25 in. diameter.

PHELPS DODGE COPPER PRODUCTS CORPORATION

GENERAL SALES OFFICES: 40 WALL ST., NEW YORK

MILLS: Bayway, N. J. • Yonkers, N.Y. • Fort Wayne, Ind. • Los Angeles, Calif.

With electric motors for a bomber's accessory equipment ranging into dozens of horsepower, considerable electricity has to be distributed to many points throughout the plane. Bus systems have become regular networks—"like all downtown", says one engineer—so that their weight introduces a serious problem.

Aluminum buses, in the sizes and forms pictured above, are helping to take care of this weight problem. For aluminum, as you know, though high in current-carrying capacity, is likewise light in weight. Aircraft engineers are profiting by the properties of aluminum which long ago led electrical men to adopt it for *their* power lines and buses.

Whether your specialty is airplanes, power lines, heavy machinery, walkie-talkies or household appliances, versatile aluminum offers you many other advantages. It is nonmagnetic, nonsparking and nontoxic. It is an excellent conductor of heat and reflector of light. Its ability to resist corrosion is, of course, well-known.

Manufacturers of materials for war are constantly discovering new ways of bettering their products by employing Alcoa Aluminum. Our engineers are available for assisting in this work. ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh, Pennsylvania.

RATED VOLTAGE is always available to equipment protected with built-in CONSTANT VOLTAGE

"Operate at 115 volts" on the label of electrically operated precision equipment is not simply informative —*it's a warning!*

A *warning* that the device is too sensitive to tolerate the voltage fluctuations that may be met on America's power lines, and still perform with efficiency. A *warning* that sensitive tubes and other delicate mechanisms may be irreparably damaged by line surges and that costly replacements, with consequent loss of time and efficiency, lie ahead.

The design engineer who assumes that the precisely controlled voltages of the research laboratory will be duplicated in the field is heading his product toward trouble. Nominal line voltage ratings can no longer be used as single, stable reference points for design considerations. Commercial power lines are too heavily loaded and unpredictable.

"Operate at 115 volts" is no longer sufficient on a label. A guarantee that the "115 volts" will always be available, in spite of the unpredictable fluctuations of commercial power, is a prime requisite if the device is to perform with unfailing efficiency and precision.

The place to provide voltage control is within the equipment. With a Constant Voltage Transformer as a component part, the device is provided with a dependable source of voltage and unfailing protection against performance interference and construction damage.

SOLA Constant Voltage Transformers are available in sizes and capacities to meet design requirements of any electrically operated equipment or electronic device. Items so protected will deliver as efficiently in the field as under the most ideal laboratory conditions.

SOLA Constant Voltage Transformers have no moving parts to get out of order. There are no manual adjustments to be made. They perform instantly and automatically, maintaining output constant to within ± 1% of the rated voltage, regardless of line fluctuations as great as 30%.

SOLA
Constant Voltage Transformers

To Manufacturers:
Built-in voltage control guarantees the voltage called for on your label. Consult our engineers on details of design specifications.
Ask for Bulletin ACV-74

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. **SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago 14, Ill.**

THE SEARCH THAT NEVER ENDS

IN THE industrial life of America, research has been of constantly increasing importance. And today it is a national resource, for the research of industrial and college laboratories is proving its value in War.

To the Bell System, research is an old idea, for the telephone itself was born in a laboratory. Behind its invention, sixty-nine years ago, were researches in electricity and acoustics and in speech and hearing.

And, ever since, there has been a laboratory where scientists have searched to know more about these subjects; and with their associated engineers have applied the new knowledge, fitting it with all the old, to make the telephone better and better.

Their fields of inquiry have broadened and deepened through these years; they inquire into all the sciences and engineering arts which have any promise of improving the telephone. Much has been learned but still more will be, because their search goes on. That is why the telephone laboratory grew to be Bell Telephone Laboratories, Incorporated, the largest industrial laboratory in the world. And it exists to improve telephone service.

Improvements in industry can be left to chance in the hope that some one, sometime, will think of something useful; that some good invention will turn up.

The other way to make improvements is to organize so that new knowledge shall always be coming from researches in the fundamental sciences and engineering arts on which the business is based. From that steady stream will arise inventions and new methods, new materials and improved products.

This is the way of Bell Laboratories. Its search will never end. And as fast as it can the Laboratories will apply its new knowledge practically to the design of equipment and communication systems.

At present—and this started before Pearl Harbor—its trained scientists and engineers and all their skilled associates are concentrating on products of importance to our armed forces. But when this work is happily over they will be ready to continue their developments for the needs of peace.

BELL TELEPHONE SYSTEM

"Research is an effort of the mind to comprehend relationships no one has previously known; and it is practical as well as theoretical." . . . . . BELL TELEPHONE LABORATORIES

AMERTRAN HIGH VOLTAGE TEST SETS

test insulating materials easily accurately!

(Below at right) Type No. TS 15; 5 KVA., 60 cycles, 220 volts input/ 0-50,000 volts secondary.

(Below) Type No. TS-1A; 5 KVA., single phase, 60 cycles, 220 v. input/ 12,500-25,000-50,000 output.

(Above) Type No. TS-1A; 25 KVA., single phase, 60 cycles, 208 v. input/ 25,000-50,000-100,000 v. output. Fully insulated.

(Left) Type No. TS-3; ½ KVA., single phase, 60 cycles, 115 v. input/ 0-1500 volts secondary.

THE capacity of AmerTran High Voltage Test Sets to test insulating materials insures economy and increased production for purchasers. Because of their versatility, one AmerTran Test Set may often replace three units of other types.

They are precise over a wide range of voltages yet capable of control in small increments. Through their simplicity, safety, ease of operation and calibration retention, they reduce observation errors.

The TS series, comprising stationary, mobile and portable units, covers a range of dielectric strength testing from transformers and cables to small apparatus, paints and fabrics. All sets function with laboratory accuracy.

Used by leading universities, utilities and industries, they represent the culmination of the skill and experience of the American Transformer Company, pioneer makers of dielectric strength testing apparatus since 1903.

AMERICAN TRANSFORMER COMPANY

178 EMMET STREET, NEWARK 5, NEW JERSEY

Pioneer Manufacturers of Transformers, Reactors and Rectifiers for Electronics and Power Transmission

AMERTRAN

THESE 7 SOLUTIONS MAY SOLVE 700 OTHER PROBLEMS...

...perhaps your own

"BAKELITE" PLASTICS—Problem Solvers for Industry

When one manufacturer solves a wartime production problem by using the right BAKELITE plastic, the result may be helpful to many other manufacturers. In this spirit, we pass along here the solutions to seven typical problems, any one of which may provide the answer to yours. The plastic materials discussed are, of course, available only for highly essential uses.

Do you have a tough coatings problem? In recent tests, steel panels coated with a BAKELITE resin primer showed no blistering, pimpling, or rusting after 8,000 hours of continuous water immersion, while other primers failed at 300 hours.

Does the molding of pieces thicker than ⅛ inches, using thermosetting materials, interest you? Heatronic molding, a recent development of the Bakelite Laboratories, makes this possible, speeds curing time 10 to 50 per cent, drops molding pressure 30 to 40 per cent.

These examples are typical of the scores of developments you will be posted on if you keep in touch with Bakelite Plastics Headquarters. Our Engineering Staff and Development Laboratories have amassed a wealth of data that can help you now with your essential production problems, or with your plans for the days to come.

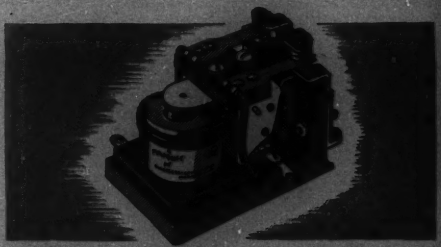
Write for specific technical literature. Please address Department 5.

BAKELITE CORPORATION

Unit of Union Carbide and Carbon Corporation

UCC

30 EAST 42ND STREET, NEW YORK 17, N.Y.



A manufacturer, wishing to eliminate the assembly of several parts normally required in small relay construction, designed an improved relay for which the base and stationary contact support were to be molded in one piece. A BAKELITE general-purpose molding material was specified for this unusual and complex construction. This material provides the desired dielectric qualities and fine finish. It also withstands the severe vibration encountered in aircraft and shipboard installations, as well as salt atmosphere and wide temperature variations —from 60 deg. F. below zero to 180 deg. F. above.

Today, plywood can be made sturdy, durable, waterproof, and weather-resistant—with BAKELITE phenolic resin glue. Wartime applications, such as the plywood airplane and glider, Army truck bodies, and Navy PT boat sections have demonstrated these properties. Recently, carloads of BAKELITE phenol-bonded plywood were sent abroad to make pontoon bridges—stub-nosed boats that will float on rivers for months at a time, withstanding weathering and hard wear.

Useful Literature on Plastics

BOOKLET 5-A "BAKELITE BEGINNINGS"—This pamphlet provides a brief introduction to BAKELITE plastics. Describes the origin of plastics . . . their forms, fabricating techniques, and applications.

BOOKLET 5-P "A SIMPLIFIED GUIDE TO BAKELITE PLASTICS"—A 16-page, illustrated booklet that describes, in digest form, the various types of BAKELITE plastics and synthetic resin products.

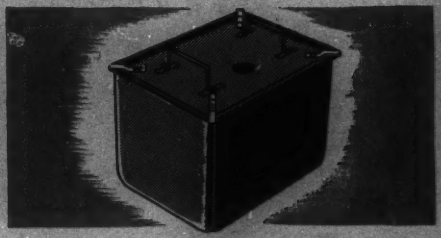
BOOKLET 5-M BAKELITE MOLDING PLASTICS"—A 32-page illustrated reference booklet. Gives technical descriptions of the various BAKELITE thermosetting and thermoplastic molding materials.

"MOLDING TECHNIC FOR BAKELITE AND VINYLITE PLASTICS" (Price $3.50)—A 224-page manual on the art of molding plastics. Contains latest technical data the designer, engineer, molder, and user should know about designing and fabricating hot-set and cold-set molding materials.

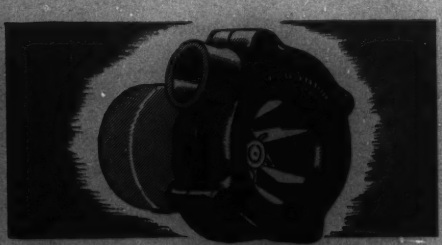
BOOKLET 5-L "BAKELITE LAMINATED PLASTICS"—A 24-page illustrated booklet. Describes, in detail, various

AN INTERESTING FEATURE of the huge Curtiss Commando troop transport plane is its use of an extremely lightweight, yet tough and durable antenna and pitot tube molded of low pressure using a BAKELITE laminating [illegible] to provide strength needed to withstand pressures encountered in flight. The [illegible] pitot tube is made using a special [illegible] BAKELITE plastic [illegible] with BAKELITE plastic [illegible] so that it can [illegible] [illegible] resisting compound, the finished [illegible] high mechanical strength.

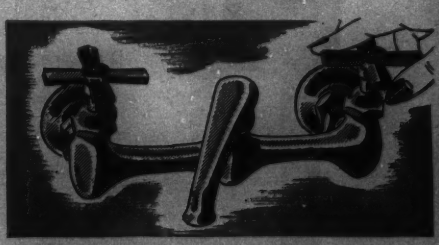
New, lighting fixture sockets aboard America's Victory Ships are molded of BAKELITE phenolic plastics. They are lighter, more compact, and more durable than sockets previously used. The manufacturer found that less breakage and faster assembly made possible a production jump of 10 to 15 per cent . . . pushed costs down 10 per cent. The new socket has been approved for use aboard all ships of our Merchant Marine, where it will withstand vibration and extremes in temperature change.



The lining of the food containers used in Medical Corps hospital food carts must stand up against constant scraping with ladle or spoon when serving, and sudden temperature changes on sterilizing. That's a tough assignment for any coating. Yet a BAKELITE resin baking finish does the job—and does it well. Known best before the war for its use in insulating and bonding armature and coil windings, these glasslike coatings have passed many rigid requirements in meeting today's wartime needs in replacing plated linings for cans, drums, and tanks.



A tiny blower measuring only four inches in diameter, weighing only four ounces, cools the radio and other electronic equipment on America's fighting aircraft. Using a BAKELITE general-purpose phenolic molding material, the manufacturer has been able to mold the lightweight blower housing to close tolerances, yet secure good heat resistance and mechanical strength.



Army, Navy. Federal housing developments, and Navy and Maritime ships are using plumbing accessories molded of BAKELITE cellulose acetate. Five hundred thousand faucet handles have already been produced—and are proving highly successful because of their low heat transmission, good heat resistance, fine appearance, and resistance to corrosion. Other developments include a shiny white elbow, for toilet flush tanks that will not shrink or distort in service.

types of laminated plastics made with BAKELITE laminating varnishes, and illustrates many applications. Outlines fabricating techniques, and gives ASTM data.

BOOKLET 5-V "BAKELITE HEAT-HARDENABLE VARNISH, ENAMEL, LACQUER, CEMENT" — A 40-page illustrated booklet. Describes resin-baking coatings and bonding materials—their properties, uses, and advantages.

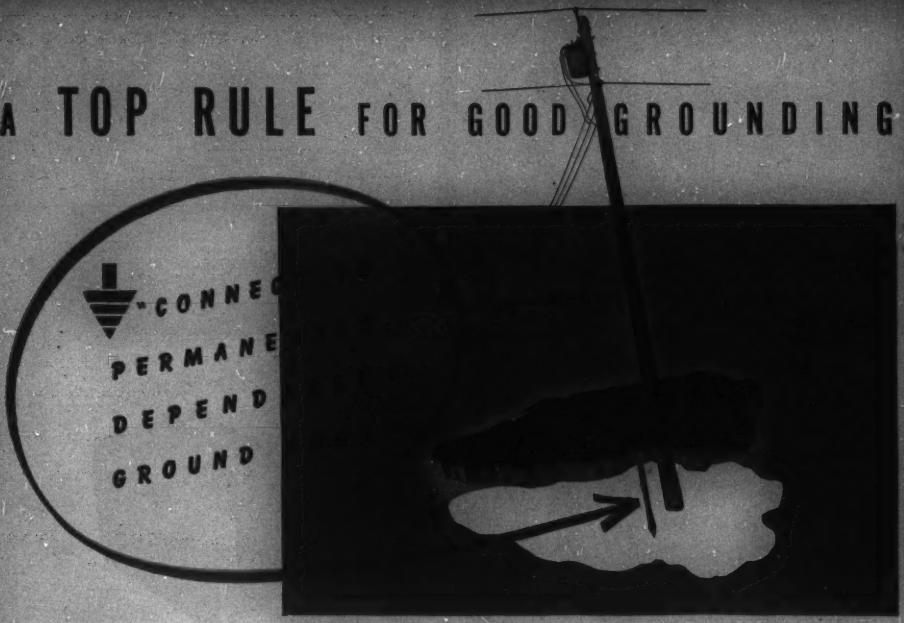
BOOKLET 5-F "BAKELITE C-9 RESINS" —A 12-page illustrated booklet for the paint and varnish technologist. Shows how these new resins accelerate bodying time and improve performance of many surface coatings.

BOOKLET 5-I "BAKELITE COATING PRODUCTS" — A 4-page folder for the paint and varnish technologist, describing the new water emulsions based on C-9 resins.

BOOKLET 5-Q "BAKELITE SEALING SOLUTIONS FOR POROUS CASTINGS" —A 4-page folder that tells how to reclaim porous and spongy castings by impregnating with resin-baking solutions.

BAKELITE

A TOP RULE FOR GOOD GROUNDING



If ground rods were uprooted, you would see the tens of thousands of Copperweld ground rods giving dependable service today. The stiff steel core that makes driving easy is protected from rusting by a thick exterior of copper. And when a copper ground wire is clamped to a Copperweld ground rod, there are no dissimilar metals in contact—the connection is "copper-to-copper."

Copperweld rods can be delivered immediately on orders conforming to priority regulations. For all your grounding requirements, present and future, plan to use a permanently dependable Copperweld rod.

Copperweld

PERMANENTLY DEPENDABLE

GROUND RODS

COPPERWELD STEEL COMPANY · GLASSPORT, PA.

ELECTRICAL ENGINEERING

Registered United States Patent Office

JANUARY
1944

The Cover: Interior view of five-megacycle induction electronic heating unit capable of continuously delivering 25-kw output. Photo courtesy Federal Telephone and Radio Corporation

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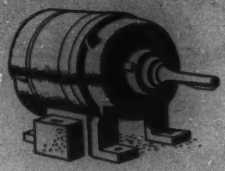
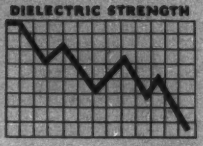
1 ***Moisture can play hob around electrical equipment.***



2 ***It can be absorbed into the insulation and lower its dielectric strength.***



3 ***It can eventually result in all sorts of maintenance misery, as every engineer too well knows.***

4 **BUT THERE'S A PRACTICAL SOLUTION TO THE MOISTURE PROBLEM!**

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ELECTRICAL INSULATION

Electrical Sinews for the Big Inch Pipe Lines

MERRITT A. HYDE
ASSOCIATE AIEE

THE NEW 24-inch oil-pipe-line project, the Big Inch, the greatest in the realm of petroleum transportation, has been carried to rapid completion under wartime conditions of engineering and construction, as a vital factor in the war effort. In fact, "Big Inch" has become another American byword of construction accomplishment.

From the viewpoint of power application, Big Inch is a 1,400-mile underground conduit, 24 inches in diameter for 1,264 miles of its length, from Longview, Texas, to Phoenixville, Pa., where it divides into two 20-inch lines, one branch to the Philadelphia area, totalling some 40 pipe miles, the other about 90 miles to the New York area.

The route encounters all varieties of terrain ranging from the Mississippi bottoms to the ridges of the Alleghenies. Between an elevation of 313 feet at Longview and seaboard at its eastern termini, its highest point is the 2,920-foot Laurel Hill crossing, in Pennsylvania.

When operating at its ultimate capacity, the line will carry a continuous 1,400-mile column of oil from Longview to Linden, N. J., more than 4,000,000 barrels of it, weighing 600,000 tons, moved at a speed of about 4¼ miles per hour. To accomplish this requires a total propelling force equivalent to about 2,450 tons. This force and rate of motion represent the continuous expenditure of nearly 100,000 horsepower—by that measure one of man's greatest pumping jobs.

This task is performed by electrically driven centrifugal pumps. The aggregate installed electric-motor capacity, applied to main-line pumping, is approximately 125,000 horsepower. This capacity is in 83 units of 1,500 horsepower each, in essentially 28 stations at intervals averaging about 50 miles, three units per station. Additional spare and auxiliary units bring the total installed horsepower to about 130,000.

In these days of big numbers, installation of 130,000 horsepower of power equipment in a pumping plant might be announced with some eyebrow lifting, but not with much breath-taking effect. The real interest in this project is in its nature, not its size. It is one thing to build and run a 130,000 horsepower pumping plant on some particular site. It is quite another matter to design, construct, and operate the equivalent capacity in 28 stations interdependent in the performance of a single operation yet extended over a 1,400-mile strip of ground.

The 24-inch pipe line, the Big Inch, will transport 300,000 barrels of crude petroleum 1,400 miles daily from the heart of Texas oil fields to the Eastern Seaboard. The new 20-inch refined-products line is 150 miles longer and has a capacity of 235,000 barrels per day of refined products. Power supply, substations, motors, and controls of the operating equipment, as well as high lights of the construction problems are discussed in this article by an outstanding authority on electrical problems associated with oil pipe lines.

The whole character of pipe-line operation stems from this subdivision into stations separated geographically but joined physically. The use of a number of stations along the line instead of one station at the origin of the line is dictated by the necessity of limiting the station delivery pressure to a value that develops a piping stress within the allowable limit. If the pumping capacity on the 24-inch crude line could be combined into one station at Longview, delivering 300,000 barrels per day through the 1,264 miles of 24-inch line to Phoenixville, with a pressure drop per mile of 12 pounds per square inch, and against a static head of 50 pounds per square inch due to difference in station elevations, then Longview station would have to operate with a discharge pressure of 15,250 pounds per square inch. Of course, this is an impractical condition from the standpoint of pipe design alone. But by dividing this pumping job among 24 stations along this portion of the line, the average net differential pressure input at each station becomes about 635 pounds per square inch. Allowing for a suction pressure at each station of 50 pounds per square inch, the station discharge pressure would be 685 pounds per square inch. In actual operation, capacity flow is somewhat higher than the 300,000 barrels per day nominal rating of the line, and the net differential pressure at each station is in the neighborhood of 675 pounds per square inch. With a suction pressure of 50 pounds per square inch, this means a maximum line pressure at the station discharge of 725 pounds per square inch, a practical value from the standpoint of pipe design.

The average spacing for 24 stations over 1,264 miles of line is 52.5 miles. Actually distances between stations vary from 31 to 78 miles, the spacing being closer for uphill and wider for downhill terrain. In each case the spacing is such that the pressure increment developed by the station is equaled by the static-head difference between that station and the succeeding station, plus the friction drop at capacity flow for the length of piping between the two stations. Figure 1 is a diagram illustrating this point.

This profile for a section of pipe line does not apply to the Big Inch right of way, but it will serve as a basis of discussion. The line throughput is taken as 300,000 barrels per day of oil with specific gravity 0.85, with a friction drop per mile of 12.0 pounds per square inch or 32.6 feet head. Minimum allowable station suction pressure is taken as 50 pounds per square inch, or 135 feet head. The net pressure increment at each station is taken as 635 pounds per square inch or 1,725 feet head. If one proceeds from station *A*, it is evident that the site of station *B* is determined by the location at which the suction head

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Essential substance of an address presented before the power group of the New York Section of AIEE, in New York, N. Y., October 14, 1943.

Merritt A. Hyde is petroleum and chemical engineer, industry engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

The author acknowledges the assistance of Oscar Wolfe, chief engineer, and A. S. Manneke and J. L. Gates, electrical engineers of War Emergency Pipe Lines, Inc., in the preparation of this article.

reaches the established minimum value of 135 feet. This spot is 33.8 miles from station *A*, the trend of the terrain being uphill. If one proceeds from station *B* in the same manner, but with generally downhill terrain, the suction head limit for station *C* is reached at a distance of 58.7 miles—substantially greater spacing than for the uphill terrain between stations *A* and *B*.

For a given capacity, fluid condition, and pipe condition, the friction pressure drop per mile is fixed. For interchangeability of pumping equipment it is highly desirable to maintain essentially uniform station incremental pressures throughout the line. Under these conditions the station sites are determined quite rigidly by the hydraulics of the line, and their selection is not subject to appreciable flexibility in the interest of convenience in other respects. This fact is important in regard to power service; it means that station locations cannot be chosen to facilitate

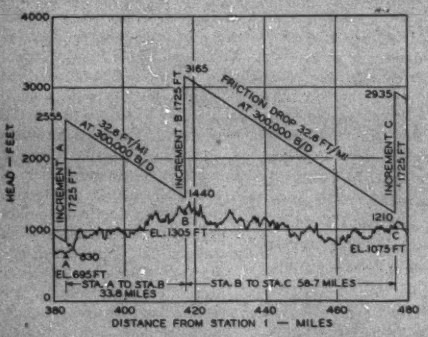


Figure 1. Typical pipe-line profile and pressure-gradient chart

Station locations are determined by the minimum allowable incoming pressure

power service, rather, power-service facilities must be extended to station sites as determined by pipe-line hydraulics.

In the course of 1,400 miles of right of way, it is to be expected that a variety of power-service conditions would be encountered. Power is delivered to the station sites by 17 different utility companies, involving new line constructions varying from a few miles up to, in one instance, 120 miles of line for serving three stations. Service voltages range from 22 to 110 kv. In all stations the bus voltage is 2,300, stepped down from service voltage through one three-phase transformer rated, in general, 3,750 kva with provision for future addition of air-blast equipment, which will permit realization of 5,000 kva capacity. The transformer primary windings are provided with undervoltage taps for adjustment to deliver the required station bus voltage under conditions of reduced line voltage. The transformer-substation installation includes primary disconnect switch, lightning arresters, and fuses.

Figure 2 is a view of the power-service facilities at one of the Big Inch stations receiving power over a 110-kv transmission line. Figure 3 is a diagram showing more clearly the arrangement of power-service facilities and is typical as well for the station switchgear, motors, and pumps. From the outdoor substation, power enters the

Figure 2. View of typical pumping station and 110-kv substation

The 3,750-kva three-phase transformer delivers power at 2,300 volts to the station bus and the auxiliary power and lighting transformers (center)

pumping-station switchgear at 2,300 volts. In this switchgear it passes through a main breaker and thence to a bus from which it is tapped to each motor through suitable starting equipment.

This starting equipment is of the full-voltage type wherever the power-service facilities are adequate to handle the across-line starting current of the motors, which is about 1,500 amperes or five times full-load current. In 14 of the 28 stations, reduced voltage starting was deemed necessary, and the equipment in these stations is of the autotransformer type providing closed-circuit starting transition. If a tap voltage of 65 per cent is used, the starting demand from the 2,300-volt bus becomes about 740 amperes. Higher starting taps are provided—and generally used—to insure delivery, even with substantial drop in the primary voltage, of sufficient voltage to the motor to enable it to develop the torque required to accelerate the pump.

The pump-accelerating torque requirement is minimized by the practice of starting with suction valve open and discharge valve closed. The static torque is less than 20 per cent, and the load torque increases as the square of the speed, from substantially zero after breakaway to about 45 per cent at full speed with the discharge valve closed. After the unit reaches full speed, the discharge valve is opened, and normal running load ensues. These motors, having pull-out torque about twice full-load torque, can carry the pump at full load through a substantial

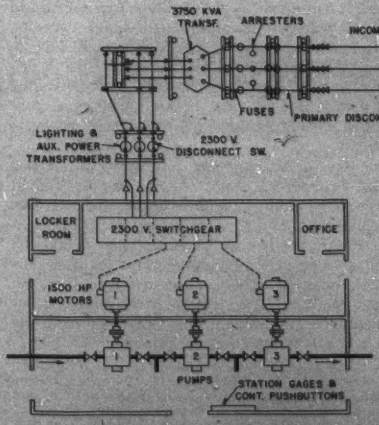


Figure 3. Diagram showing electric-power service and main circuits in 24-inch-line pumping station

voltage dip—down to a voltage approximately 70 per cent of normal. Within that range the starting of one unit does not affect appreciably the operation of other units which may be running. This means that for a particular pumping station the choice between across-line starting and reduced-voltage starting is determined by the ability of the power system to handle the starting demand with acceptable voltage service to other power users on the system.

A typical installation of full-voltage starting switchgear is shown in Figure 4. The two left-hand units house the potential and operating transformers and the main circuit breaker, with metering and relaying for the incoming line. The remaining three units each control one 1,500-horsepower pump motor.

Each motor control unit provides time-delay undervoltage protection, and also instantaneous short-circuit protection and locked-rotor protection. Running load protection is provided by a thermal relay which follows closely the heating characteristic of the motor.

The switchgear is of the metal-clad vertical-lift breaker type, with the well-known features of safety, interchangeability, and complete factory assembly—outstanding advantages for pipe-line station service. All circuit breakers are 7.5 kv, 100,000 kva interrupting rating, 600 amperes for the motor units and 1,200 amperes for the incoming line. A spare 1,200-ampere breaker is interchangeable in all the units.

Figure 4. Metal-clad switchgear controlling 2,300-volt incoming line and three 1,500-horsepower pump motors using full-voltage starting

The circuit breakers, mechanically interchangeable, are easily removed and replaced

Figure 5 shows reduced-voltage switchgear and three 1,500-horsepower 1,780-rpm motors driving main-line pumps, each through a stuffing box in the fire wall separating the pump room from the motor room.

These motors are of the squirrel cage induction type, rated 40 degrees centigrade rise open. Their ventilation is by air intake at both end brackets, with discharge through an opening in the top of the motor frame. Each motor is installed with a so-called "top hat" through which the warm discharge air is drawn into a duct and expelled through the roof by a small motor driven blower. Provision is also made for circulation of this air as a means of heating the station in cold weather.

The motor room is completely separated from the pump room by a fire wall, with no communicating doorways, it being necessary to go outside the building when passing from the one room to the other. With this arrangement the motor room is considered nonhazardous, and the equipment and installation in this room are of conventional type for nonhazardous location.

Figure 5. General view of motor and control room showing reduced-voltage starting switchgear and three 1,500-horsepower pump motors

Shaft seal in wall separates motor room from pump room

The pump room, however, is considered hazardous. Figure 6 shows the pump room with the three units, arranged in series, the incoming flow entering the suction valve of unit 1 in the foreground. The pumps are surprisingly compact, being single stage, 16 by 12, rated 8,750 gallons per minute, 648 feet head, at 1,780 rpm. The discharge valve of unit 1 can be seen just beyond the pump, followed by unit 2 with its valves, and in turn by unit 3 and valves.

From the standpoint of electrical devices and wiring, the pump room as mentioned previously is a hazardous atmosphere location, made so by normal drainage from the pump glands, by pump-casing venting operations, and by any abnormal leakage from pump glands, valves, piping, and fittings. The push buttons in the pump room for starting and stopping of the units are of the explosion-proof type. Likewise the pressure-protective relays, of which more will be said later.

The suction and discharge valves associated with each pump are manually operated, the 16-inch suction valve requiring 156 turns for its complete travel and the 12-inch

Figure 6. View from suction end of pump room in a Big Inch station, showing the three pumps connected in series

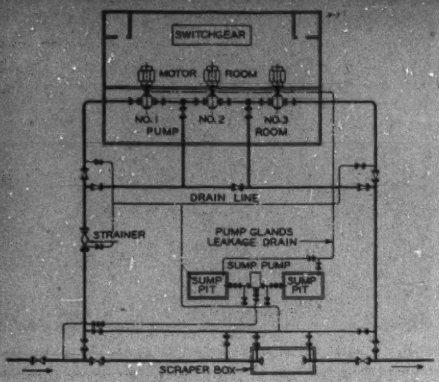


Figure 7. Piping diagram for a typical Big Inch station

discharge valve 118 turns. Rapid operation of these valves taxes the physical capacity of one man, and it seems probable that they will be converted to motor operation when the availability of such apparatus becomes less critical.

The co-ordination and control of the many component parts of a typical station are an important problem. The main 24-inch line enters and leaves the station site as shown at the bottom of Figure 7, where a scraper box, interrupting the line, provides for the handling of incoming and outgoing scrapers, employed to clean the line. By suitable valve positioning, the stream is detoured through the station, where it receives the pressure increment developed by the pumps and resumes its travel along the line. Also in this diagram can be seen the suction and discharge valves of each unit and the check valves which permit bypassing the individual units or the station.

The starting and normal stopping of stations and of units within stations are by direction of the dispatcher, who is located in the headquarters office at Cincinnati. Continuous intercommunication between the dispatching office and all stations is provided by teletype with telephone available as a supplementary means.

In starting the line from complete shutdown, when all stations are in readiness, the dispatcher instructs station 1 at Longview to start one unit, and the other stations each to start one unit when the line pressure at that station begins to rise in response to the operation of the upstream stations. The operator has at a central location in the pump room, two gauges reading "station suction pressure" and "station discharge pressure" and mounted with them the three push-button stations controlling the individual units. Without having to lift his glance from the gauge he can push a start button, and within ten seconds the pump is up to speed ready for its discharge valve to be opened.

In succession the stations start unit 1 and, when all are operating with one unit, the dispatcher may call for starting unit 2 beginning at Longview and progressing throughout the line in the same way. Finally, to operate at full capacity, the dispatcher may instruct all stations to start unit 3 following the same procedure. Should conditions dictate intermediate throughputs, the dispatcher can accomplish this by holding selected units, or stations, out of service; however, in so doing he must distribute the operating capacity along the line so that suction and discharge pressures at all stations fall within prescribed limits. This requires very carefully worked-out schedules to prevent the occurrence of prohibitively low suction pressures at some stations and excessive discharge pressures at others, or to avoid undue throttling at some stations (throttling is an inefficient means of dissipating excess pressure within the station). Thus, it is apparent that flexibility in normal starting and stopping is an important contribution by electrical control to the operation of the line.

Of still more importance is the adaptability of electrical control to protective shutdown functions. As already indicated, it is necessary at all times to hold the operating pressures on the line and in the stations between definite limits of low suction and high discharge pressures.

Low suction pressure permits vaporization of the liquid with possible damage to the pump. To guard against this, a relay is provided, having its pressure element connected to the station suction. Its contacts sound an alarm at about 35 pounds per square inch, thus warning the operator, who may be able to correct conditions by throttling adjustment. Failing this, a second low-pressure relay functions at about 20 pounds per square inch to cause shutdown. Both of these devices are capable of higher or lower settings.

By suitable electrical control, the low-suction-pressure shutdown relay is arranged to stop the units in timed sequence, beginning with the downstream unit, with an interval of about five seconds between shutdowns. If upon shutting down a unit, the station suction pressure rises above the reset point of the protective relay, the remaining units are allowed to continue in operation. However, if the suction pressure persists below the protective-relay setting, the remaining units are stopped automatically in sequence at five second intervals.

Protection against excessively high line pressures at the station discharge is provided by a pressure-actuated relay, similar to the low-suction-pressure protective relay and set to function when pressure exceeds about 900 pounds

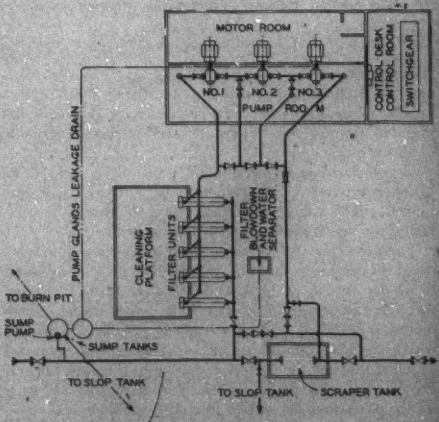


Figure 8. Piping diagram of typical station of the 20-inch refined-products line

per square inch. An additional pressure relay between unit 2 and unit 3 will allow a pressure at this point not more than 250 pounds per square inch above normal discharge pressure of unit 2. These high-pressure protective relays also will shut down successive units in timed sequence.

In event of a protective shutdown due to abnormal pressure, the operator may have difficulty in identifying the particular relay that functioned. To provide this information quickly, a visible annunciator is being designed for operation in conjunction with the pressure protective devices. This annunciator will be mounted in the pump room, in an explosion-proof housing, adjoining the station pressure gauges and the push buttons which control the three pump units.

With these protective devices, the station can operate at a wide range of pressure conditions within the limits for which the devices are set, and yet have the benefit of protective shutdown when some abnormality results in pressures exceeding the predetermined limits.

These vital protective functions are made possible in simple reliable form through the medium of electrical control. Thus, electricity provides not merely the sinews that make Big Inch a moving thing, but also the nerves that direct and protect it in the performance of its mighty task.

And now Big Inch has a rival, the new 20-inch refined-products line under completion from Beaumont, Tex., to the Philadelphia and New York areas.

Called "little Big Inch" because it's a trifle smaller in the waist, it is 150 miles longer, and it really packs a bigger wallop than Big Inch, for its 235,000 barrels per day capacity of refined products will represent the equivalent of some 370,000 barrels per day of crude oil.

Little Big Inch, drawing products from ten refineries in the Baytown and Beaumont areas, runs 350 miles to Little Rock, Ark., where it joins the right of way of the 24-inch line and follows it from there on to the East. Beginning at Little Rock the 20-inch-line stations are at the same sites as the stations on the 24-inch line. Thus substantial savings are effected in costs of right of way, station sites, power procurement, energy, operating labor, and operating maintenance.

Station layout on the 20-inch line, as indicated by Figure 8, will be quite similar to that of the 24-inch line. However, the handling of refined products entails the addition of filter units.

Power-service facilities are entirely similar to those of the 24-inch line. Transformers of 3,750-kva rating are being installed, the two transformers at each site to operate in general from a common primary feeder with independent secondary circuits to the respective pump houses.

Ultimately it is likely that a 2,300-volt bus tie will be installed with a normally open switch. Upon failure of either of the transformers, closure of this bus tie would permit both stations to be loaded from one transformer which, cooled by air blast, would permit operation of selected units in both stations.

Main switchgear for the 20-inch-line stations is interchangeable with that of the 24-inch line. An additional matching unit houses the station sequence control to be described later.

The three pump units are driven by 1,250-horsepower motors at 3,575 rpm, similar to the 24-inch-line motors in ventilation arrangement. A principal feature of the motor construction, is the provision of flood lubrication by a shaft-driven oil pump. Like the 24-inch-line motors, these units are co-ordinated as to mounting dimensions, so that all main pump motors on the 20-inch line are mechanically interchangeable, regardless of manufacture.

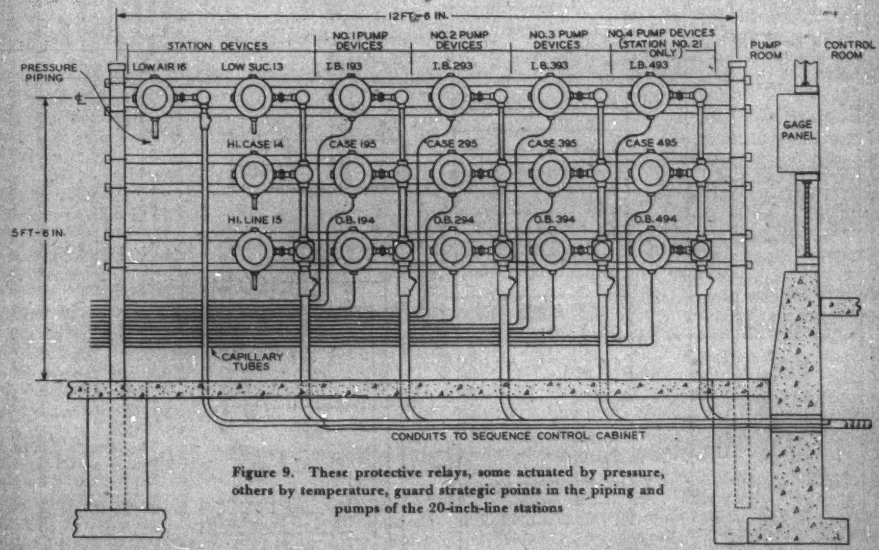
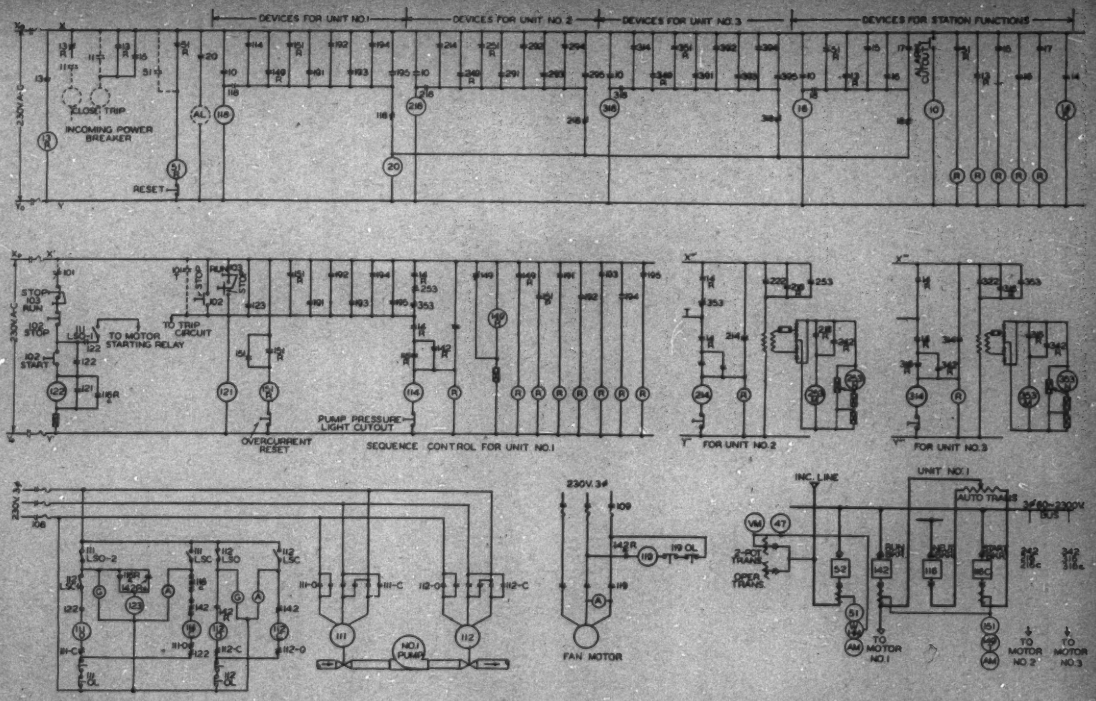


Figure 9. These protective relays, some actuated by pressure, others by temperature, guard strategic points in the piping and pumps of the 20-inch-line stations



(A)—Amber indicating light on control desk

(G)—Green indicating light on control desk

(R)—Red indicating light on control desk

AL—Audible alarm

10—Alarm cutout relay

11—Control switch for incoming line breaker

13—Low-station-suction-pressure protective relay

13R—Auxiliary relay to 13 (shown with pressure on suction line)

14—High-pump-pressure protective relay

14R—Auxiliary relay to 14

15—High-station-discharge-pressure protective relay

16—Low-air-pressure protective relay

17—High-sump-level protective relay

18—Auxiliary alarm relay

20—Alarm relay

47—Reverse phase relay

51—Overcurrent relay of incoming line breaker

51R—Auxiliary relay to 51

51 Reset—Reset push button for incoming-line overcurrent auxiliary relay

52—Incoming line circuit breaker

101 (201, 301)—Control switch for motor, trip-permissive

102 (202, 302)—Motor start-stop push button on control desk

103 (203, 303)—Motor stop-run push button, at pumps

108 (208, 308)—Valve motor breaker

109 (209, 309)—Fan motor breaker

111 (211, 311)—Suction-valve motor

111-C (211-C, 311-C)—Suction-valve contactor—close

111-O (211-O, 311-O)—Suction-valve contactor—open

111-LSC (211-LSC, 311-LSC)—**Suction-valve limit switch—closed limit

111-LSO (211-LSO, 311-LSO)—**Suction-valve limit switch—open limit

112 (212, 312)—Discharge-valve motor

112-C (212-C, 312-C)—Discharge-valve contactor—close

112-O (212-O, 312-O)—Discharge-valve contactor—open

112-LSC (212-LSC, 312-LSC)—**Discharge-valve limit switch—closed limit

112-LSO (212-LSO, 312-LSO)—**Discharge-valve limit switch—open limit

114 (214, 314)—Auxiliary relay to 14

116 (216, 316)—Magnetizing breaker of motor switchgear

116C (216C, 316C)—Starting breaker of motor switchgear

116R (216R, 316R)—Auxiliary position relay for magnetizing breaker of motor switchgear

118 (218, 316)—Auxiliary alarm relay

119 (219, 319)—Fan-motor control contactor

121 (221, 321)—Lockout relay

122 (222, 322)—Sequence relay

123 (223, 323)—Sequence relay

142 (242, 342)—Running breaker of motor switchgear

142R (242R, 342R)—Auxiliary position relay, for running breaker

149 (249, 349)—Motor winding-temperature. Alarm relay

149R (249R, 349R)—Auxiliary relay to 149 (249, 349)

149T (249T, 349T)—Motor thermal overload relay

151 (251, 351)—Overcurrent relay of motor switchgear

151R (251R, 351R)—Auxiliary relay to 151 (251, 351)

151 Reset (251 Reset, 351 Reset)—Reset push button for motor overcurrent auxiliary relay

(253, 353)—Sequence timing relays for high-pump-pressure tripping

191 (291, 391)—Motor outboard bearing temperature protective relay

192 (292, 392)—Motor inboard bearing temperature protective relay

193 (293, 393)—Pump inboard bearing temperature protective relay

194 (294, 394)—Pump outboard bearing temperature protective relay

195 (295, 395)—Pump-casing temperature protective relay

VM—Voltmeter

AM—Ammeter

WHM—Watt-hour meter

**Valve-limit-switch positions are shown for both valves in closed position. Limit switches LSC change position at closed end of travel and limit switches LSO change position at open end of travel

Figure 10. Schematic diagram of station sequence control for 20-inch products line, three-station unit, using reduced-voltage starting

Except for those devices shown in broken lines, the main switchgear is not included in this diagram Symbol identification

The pumps are single stage, 14 by 12, operating three units in series to handle 235,000 barrels per day of gasoline developing a total pressure of approximately 750 pounds per square inch.

The principal differences in the 24-inch and 20-inch station designs lie in the system of station control, occasioned largely by the greater precision justified in products-line operation to minimize contamination between products. The suction and discharge valves of each pump are motor operated, and the complete pumping unit, with valves, is controlled by a single "start-stop" pushbutton.

Protective relays actuated by pressure and temperature are used somewhat more extensively in the 20-inch-line stations. In addition to low-station-suction-pressure and high-station-discharge-pressure protection, there is a pressure relay connected immediately upstream of the station throttling-control valve. If excessive pressure occurs at this point, this relay stops whichever unit is operating as the final unit in the station, and, if pressure conditions are not restored to normal within some three seconds, then it proceeds to stop the next unit in time sequence, and finally, if abnormal pressure still persists, it stops the remaining unit.

Temperature-actuated relays are employed in all pump casings, pump bearings, and motor bearings, and on the motor windings.

Figure 9 shows the method of installing the pressure and temperature protective relays associated with equipment in the pump room. It will be noted that each relay is in an explosion-proof housing.

In general each protective relay actuates circuits to perform three functions:

1. Sound an alarm.

2. Energize an indicating light to identify the protective device that operated.

3. Stop the unit, or the station. Certain relays provide alarm and light signal only, leaving corrective action to the operator. This is true in the case of high temperature in motor windings, high level in the sump to which gland leakage is drained, and low air supply to the pressure controllers.

The scheme of control for performing these functions is shown in Figure 10. Because of the unusual interest in this control, this drawing, of more than usual detail, is included.

A feature in line with recent practice on other products pipe lines is the provision for throttling at the station discharge under automatic control by pneumatic controllers. This system is designed to throttle the station discharge when necessary to maintain the station suction pressure above a predetermined low limit, say 30 pounds per square inch, or to maintain the line pressure beyond the station discharge below a predetermined pressure, say 800 pounds per square inch. This system is also useful in bringing pumping units onto the line, as it provides regulation of the maximum station discharge pressure to the discharge control instrument setting. When a unit is placed into service, this setting can be adjusted readily to limit the effective station increment pressure initially to substantially the value that existed before starting the unit. Then the station increment can be raised gradually by reduction in throttling, thus making the additional pump pressure effective on the line with minimum hydraulic disturbance. This procedure avoids shutdowns during starting operations, that otherwise might result from pressures exceeding the allowable range with consequent functioning of the protective relays.

Nerve center for all these control operations and protective functions is the station control desk and the associated sequence-control cabinet. Figure 11 shows how the several circuits from the pump and motor rooms—from the lockout push buttons, the motor operated valves, and the protective pressure and thermal relays—all converge in the station sequence-control cabinet. In it are assembled the necessary relays to translate the incoming impulses into proper action by the switchgear, valves, auxiliary blower controls and, when necessary, the station alarm. At the same time the station sequence-control equipment sets up proper circuits to the control desk to keep the operator informed by indicating lights as to the functioning of the various apparatus.

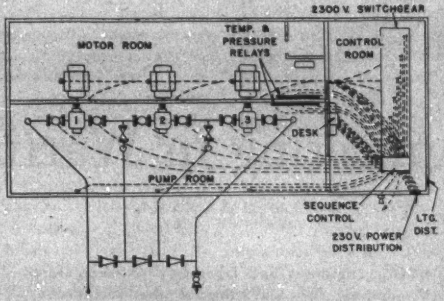


Figure 11. Typical conduit layout for power and control wiring in a 20-inch-line station

From the station control desk all major operations of station control are performed. Installed in the partition between the control room and the pump room, it is surrounded by a large glassed area permitting view of the pump room and motor room. To facilitate this view, the gauge-panel section is designed low, so that the operator can look over the top of the unit.

The gauge-panel section consists of a compartment having rear doors opening into the pump room to permit servicing the hydraulic instruments. The front is a panel surface facing the control room, on which the instruments are mounted with gaskets. This gauge-panel compartment is gasketed into the partition to prevent seepage of hazardous vapors into the control room, and, as an additional precaution, the control room is kept under a small pressure of clean air drawn from the outside of the building.

Instrumentation consists of:

Suction-pressure controller and recorder.

Suction-pressure indicating gauge.

Pressure gauge for air to pneumatic controllers.

Air-pressure-regulator adjusting valve.

Clock.

Discharge-pressure indicating gauge.

Discharge-pressure controller and recorder.

A horizontal surface below and at each end of the gauge panel provides writing space and accommodates the station log sheet.

The electrical section of the control desk is a separate unit isolated from the gauge-panel compartment, located

entirely within the control room, mounting push buttons and indicating lights for the master station control. The desk-top surface is a sheet of transparent plastic, backed with a schematic design of the main piping within the station, and showing the main-line valves, pumps, and driving motors.

From a single "start–stop" push button, the operator controls each pump unit, the valve motor control and pump motor control automatically functioning in proper sequence for starting up and shutting down. Indicating lights in the desk-top diagram show the valve positions, and small illuminated arrows show the actual course of the stream through the station piping in accordance with the particular units operating.

If trouble should develop at any of the protective-device locations, a small red indicating lamp appears at the appropriate spot in the station diagram, and the operator is given an audible signal. In addition, certain of the protective devices automatically shut down the particular unit involved, or the station. In each case, the audible signal continues until it is silenced by an alarm cutout button, and the particular indicating light burns to tell the operator exactly where the trouble is until it is extinguished by manual reset at the protective-device location, when the trouble is cleared.

This desk and the associated system of control greatly simplify the duties of the station attendant, increase the reliability of station operation, and facilitate location of the trouble spot in case of abnormal shutdown. Checking continuously the pulse and the temperature of the station equipment, the desk has been called appropriately, "pipe line nurse."

The building of the world's two largest pipe lines in a little over two years is a tremendous task. It is tremendous in tonnage of materials, in distances, and terrain, and in the co-ordination of work and supplies. To have accomplished these things in the time involved is indeed a tribute to the oil industry, its engineers, and all associates. The electrical industry is proud that within the time prescribed it could co-operate and co-ordinate its activity with the broad requirement of the oil industry, not only to supply the prime power, but also to assist in the perfection of control which has contributed and will contribute so greatly to the performance of the job.

Engineering in Wartime

L. A. UMANSKY
MEMBER AIEE

Our engineers and laboratory workers are pointing the way toward the salvation, conservation, and replacement of critical materials needed for war production, says this industrial engineer. Through their developments the quality of American industry's products has not suffered, and many lessons that will be useful in peacetime have been learned.

IN ITS BROAD and direct sense "engineering" means making the most skillful and efficient use of available materials and of human effort. War has not changed this fundamental conception. On the contrary, it has accentuated its importance.

As compared with other nations, the United States has been rather lavish in its past use of natural resources—primarily because there were so many and so much of them, and because they were considered "cheap." It has come to us as an unpleasant surprise that in this total war even *our* resources are being stretched to the limit, or even beyond this limit. Furthermore, the fortunes of war have deprived us, either fully or in part, of many other indispensable materials around which a number of our industries have been built.

It was a peacetime saying that an engineer should do for a dollar what would take others two dollars, and yet get the same, or better, results. Now, in the economy of war and scarcity, the dollar cannot always be considered as a true yardstick of accomplishment. To save a pound of copper may be more important than to save a pound of silver or gold. In short, our engineers are charged, first of all, with the task of stretching our supplies—of making one pound of copper, rubber, or tin do the work of two or more pounds.

There are three ways in which critical materials can be saved:

1. We can substitute for them other, more readily available materials.
2. We can work available materials harder.
3. We can use available materials more skillfully.

Obviously, we can combine all three methods.

How successful have been the engineers in fulfilling this task? True, the time is not yet ripe to answer this

Essential substance of an address presented at the Northeastern New York War Production Conference in Schenectady, N. Y., April 15, 1943.

L. A. Umansky is assistant manager of the industrial engineering department, General Electric Company, Schenectady, N. Y.

question in full. But we can plainly see the trends and the partial accomplishments. Being an electrical engineer, naturally I will illustrate this point by cases taken from the electrical field, even though other industries have done equally as well, I am sure.

The list of critical materials requiring alternates is long indeed. Aluminum, to cite a random example, stands high on this list. Aircraft obviously has a first call on this metal. Until the aluminum expansion program is completed, sometime in 1943, the electrical industry will not have all the aluminum it would require normally. An alternate for the cast aluminum in squirrel-cage rotors could be copper, of course, but copper is as scarce as, or scarcer than, aluminum, and making rotor copper windings would require far more labor, which is becoming the scarcest item of all. Reclaimed aluminum, not suitable for airplane construction, but with all good electrical properties, therefore is being widely used.

In many types of equipment, aluminum was employed formerly to get lightweight moving parts or to obtain an easily manufactured design, such as die casting. Many of these moving parts are now made of steel—and by thinking and working harder, the engineers and draftsmen have succeeded in most cases to change the design so as to maintain substantially the same weight. Zinc die castings also are used as substitutes. By these and similar steps, one electrical manufacturer alone has reduced his annual consumption of aluminum by some 8,000,000 pounds.

To cite another example, the shortage of tin has hurt production primarily in the manufacture of babbitt for bearings. Our prewar standard called for a composition containing 83 per cent tin. Conventional lead-base babbitt was not nearly as good. After intensive research work, a high-grade lead-base alloy was found which answered the purpose. In this manner, one manufacturer alone, will save over 200,000 pounds of tin per year.

A few others of the thousand and one critical materials for which substitutes had to be found are chromium, nickel, and nonmetals like tung oil, shellac, mica. Thanks to engineers and laboratory workers, this work has been done; the quality of American industry's products has not suffered, and many lessons that will be useful in peacetime have been learned.

But by far the most important material, without which the electrical industry could not exist at all, is copper. And copper *is* scarce. In a "normal" prewar year, an average of 2,000,000 tons of copper was used in the United States. About 40 per cent of this amount has been used for current-carrying purposes, that is, in electrical machinery, transmission and distribution lines, in radio, telephones, and telegraph. The domestic production of copper has not been increased materially. Imports from South America are subject to shipping difficulties. Hence, our supply of available copper definitely is limited. At the same time, the amount of electrical apparatus manufactured has been more than doubled and the copper requirements for other war matériel have grown by leaps and bounds. Hence, the strictest economy plainly is indicated and should be enforced rigidly.

Let us establish clearly in our minds what the saving in copper means to our war effort. We are so used to large figures that a saving of one ton of copper in a large project may sound picayune and not worth the engineer's time. What is a ton of copper? At 12 cents a pound, 2,000 pounds is only $240. But these 2,000 pounds will make 80,000 cartridge cases for machine guns or rifles. Even if only one per cent of these rounds of ammunition reach their goal, there will be 800 fewer enemies facing us, and the end of the war will be that much nearer. Therefore, it is not the cost of copper that counts, but its availability. A market quotation is a poor yardstick to measure our effort in wartime.

The use of silver instead of copper in several war plants is one of the best illustrations of this point. Silver is approximately a seven per cent better conductor than copper, but it costs about 60 times as much. In normal times, its use has been limited to such relatively small but important parts as contacts of breakers and switches and the like. The bulk of our silver reserve was buried in government vaults, useless and sterilized.

War necessity forced on us a common-sense decision. An up-to-date electrochemical plant—such as used to produce aluminum or magnesium—requires a tremendous amount of electric equipment. For instance, a so-called electrolytic potline, capable of producing 30,000,000 pounds of aluminum per year, requires 60,000 amperes of direct current at 650 volts. As much as 1,000 tons of copper would be needed to carry this heavy current from one electrolytic cell to the next one and then back to the rectifiers. Aluminum could be substituted for copper but we need this metal badly elsewhere. And so, silver was taken out of its prison, rolled into heavy bus bars, and put to work. It is revealing to watch the construction men cut and trim these silver bars, and throw them around, seemingly without any respect, as if this were mere copper. True value shows up in an emergency.

But, interesting as this experiment is, we should not look to silver as an answer to our copper problem. Our supply of silver is large, if measured by the silver standards, but it is a drop in the bucket, less than two per cent of our annual copper consumption. In other words, we still must depend on copper to carry current. The problem of stretching our limited supply is still with us.

The next engineering step is obvious. Can we work our materials harder? Shall we temporarily discard our natural tendency to be conservative, and to play safe, in our designs and planning? The engineer's answer is a straightforward one.—Yes, let the equipment be overloaded if need be during this emergency. Let a 100-horsepower motor carry a 115- or 125-horsepower load; let the transformers, generators, cables, switchgear, and control carry an additional burden while the war lasts—just as our men and women in the services are doing and as our men and women on the

home front are expected to do. This is the underlying idea of the War Production Board rulings on this subject. In this way, more useful equipment can be manufactured from the materials on hand and more materials will be left for the fighting services.

A certain amount of sincere opposition to this policy was naturally encountered. Would not this overloaded equipment be less reliable? Would not the resultant failures be more costly, in terms of lost production, than the realized savings in materials? At this point, common sense should be resorted to, as it is in all engineering problems.

A motor, overloaded as recommended, will have a shorter life, say 10 instead of 20 years, but this life span should be ample to cover the expected duration of the war. But within this life span, the expectancy of troubles and failures is not increased necessarily by the recommended heavier loading. Hence, overloading of this type makes sense. On the other hand, we may deal with a turbogenerator or a main transformer well past its prime of life, but still going strong. Overloading such a machine might invite trouble due to its aged insulation. A failure might result in the shutdown of a whole industrial area. It would be poor engineering judgment to foster overloading of this kind.

The greatest engineering contribution, however, is not only in finding alternates for critical materials, not only in working them harder, but in using them more *skillfully* and *efficiently*. War has stimulated this activity as nothing else had done before. Let us take, for instance, the field of electric-power distribution in industrial plants. It was not unusual to find that electric power would be brought to an industrial plant at high voltage, stepped down at the plant boundary to the motor voltage, and then distributed throughout the plant at this low voltage. No copper mine in the world contains as much copper as is buried in the cables and conductors in our industry. Copper was cheap, there was plenty of it, and few people worried over such waste.

Engineering analysis, applied to this problem, has shown convincingly that immense tonnages of copper can be saved by distributing power at high voltage (up to 13,800 volts) within the plants and by stepping it down to utilization voltage at several load centers, through the use of relatively small transformers. In a typical plant, with a 300,000-square-foot floor area and a load demand of about 3,000 kw, as much as 10,000 pounds of copper (the equivalent of 400,000 cartridge cases) can be saved by this method alone, without even attempting any overloading of the cables or the transformers. And, incidentally, a better operating system, with closer voltage regulation and with smaller losses, will be obtained. This is not a trick, it is merely the old story of making one pound do the work of two.

Or, let me cite the case of testing aircraft engines. Each engine is loaded and run for several hours to make certain of its performance in the air. The engines are rated up to 2,000 horsepower and use high-octane gasoline. It was considered normal to load these engines on propellers on a test stand, that is, to literally throw the energy into the air and waste expensive gasoline. The engineering solution now widely used is to connect the airplane engine under test to a generator and to pump the energy back into the power system. From 3,000 to 5,000 kilowatt-hours can be salvaged for each engine tested. If all airplane engines were tested in this way, as much as 1,000,000,000 kilowatt-hours could be salvaged per year and about 75,000 fewer tons of coal would have to be mined and transported. At several engine factories, up to 60 per cent of the energy required to operate the whole plant is obtained from this regenerative source. The load on the power systems is correspondingly reduced and these systems are more readily available to serve other industries without requiring additional generating and transmission equipment.

Again this is not a mere trick, but engineering at its best—engineering applied to war effort. Examples of such accomplishments can be found in practically all branches of industry.

Engineers should accept as a self-evident truth that no effort should be wasted on anything that will not help to win this war. But this does not mean that engineering developments and investigations should be stopped during the war. On the contrary, they should be stimulated. This war, more than any other in history, is a war of machines, of engineering. The side with the best engineering will win.

Remember, also, that this is a total war, fought in our factories as well as on the battlefield. Anything that will increase the war output of our plants may well deserve an engineering study, or even an engineering development.

A large steel mill in the Pittsburgh territory is working 100 per cent on war orders. It generates its own 25-cycle power. Increased production resulted in a power shortage. A public utility was ready to make up this shortage, but its system operates at 60 cycles. A 20,000-kw frequency-changer set was needed, and needed quickly. The electrical industry could not apply such a set within the needed time because the facilities for building large rotating machinery were tied up with other important war work, such as ship propulsion and the like. Yet the problem had to be solved. An electronic frequency changer was conceived, developed, and is being rushed to completion. Here is an instance of engineering development of the highest order, extremely important even in peacetime, but intimately and directly connected with the war effort.

Such cases could be cited without end. Add to these, the tremendous engineering developments connected with aircraft, radio, fire-control, and other combat equipment and it can readily be seen that in a nation at war the engineering profession must do a double duty in blazing new trails, trying new ideas, and venturing into the unknown. In this venture, co-operative effort is needed as never before. United we will accomplish so much more than we can individually.

Physical Metallurgy of Copper and Copper-Base Alloys

P. H. BRACE

The physical metallurgy of copper and some of its alloys is of particular interest to electrical engineers, since copper is used so widely in electric apparatus. Illustrations are given in this article of certain basic metallurgical phenomena determining properties and performance of some of the more specialized alloys with particular reference to the effects of elevated temperatures.

COPPER has been prized in all ages because of its favorable working characteristics. Pure copper can be cold-worked to an astonishing degree and may be effectively annealed at moderate temperatures. These facts are illustrated in a quantitative way by Figures 1 and 2 which show the effects of cold-rolling and annealing on the yield strength of high-conductivity oxygen-free copper (copper 99.94 per cent phosphorous nil) as reported by Wilkins and Bunn (page 11, chart 26, and page 12, chart 31).

From this it may be seen that the yield strength may be increased by approximately 5 to 1 by cold-rolling and that annealing is practically completed by heating for an hour at temperatures as low as 375 degrees centigrade.

From these data it may be seen that fairly good elastic strength may be conferred on pure copper by cold-working it. It is also apparent that a large part of this strength easily may be lost by prolonged exposure to elevated temperatures. That is, the thermal endurance of pure copper is quite low.

Early workers in copper were aware of the fact that the response of copper to cold-work and annealing was not uniform. In more recent times it has been found that quite small amounts of certain metals in solid solution in copper would alter profoundly its response to annealing after cold-working.

In modern electrical apparatus the temperatures reached by buried copper may be so high that the thermal endurance of pure copper is inadequate. Consequently, the effects on thermal endurance of small amounts of alloying elements has received a great deal of attention from those interested in the design of high-duty power apparatus.

Silver, even in quite small quantities, considerably increases the thermal endurance of cold-worked copper and, fortunately, has little effect on electrical conductivity. Figures 3 and 4 show data given by Gregg[2] on the effect of various small amounts of silver on the thermal endurance of hard-drawn copper wire. Moore,[3] in a discussion of the effects of temperature on overhead transmission lines, presents data to show that at 100 degrees centigrade silver-free copper wires soften almost completely in 100 days.

Arsenic and more recently tellurium have been used to improve the thermal endurance of cold-worked copper. The effect of the latter element may be seen by comparing Figure 5 (Wilkins and Bunn, page 25, chart 69) with Figure 2. The presence of 0.45 per cent tellurium has pushed the "knee" of the curve yield of strength versus annealing temperature for one-hour anneals from approximately 290 degrees centigrade (554 degrees Fahrenheit) to 320 degrees centigrade (608 degrees Fahrenheit) an increase of 30 degrees centigrade.

These gains in thermal endurance are helpful in dealing with the effects of usual operating temperatures. However, something more is needed when higher temperatures must be dealt with and where both electrical and mechanical duties must be performed by machine components, such as slip rings, spot-welding electrodes, and fuse clips, for example, where high conductivity is required.

This "more" has been found by the metallurgist in precipitation-hardening alloys. These are distinguished from the solid-solution alloys, for example, the dilute alloys of copper with tin, zinc, and nickel, which constitute the bulk of the standard engineering alloys of copper.

In a solid-solution alloy the atoms of the solute metal replace a proportion of the solvent atoms without disturbing greatly the crystal-lattice characteristic of the solvent metal. The alloy generally is harder than the pure metal. Unfortunately, when the alloy atoms are in solid solution they exert their maximum effect in decreasing electrical conductivity. The gain in strength arising from alloying is usually much less in proportion than is the loss in conductivity.

In precipitation-hardening alloys the solid-solution condition is stable at high temperature but not at low. If such an alloy be quenched from an appropriate elevated temperature, the solid-solution condition may be retained at room temperature. This condition is unstable however, and, if opportunity is given, as by reheating and holding at an intermediate temperature, the solute atoms will group themselves to form more or less definite crystallites within the mass of former solvent metal. This is the "precipitation" phenomenon. The tendency is for the solid solution to become transformed to a mechanical mixture. It appears that in the early stages of the precipitation process the solute atoms migrate into positions which cause sufficient disturbance of the regularity of the solvent lattice to affect markedly the mechanical properties in the direction of increased hardness and elastic strength

Essential substance of a conference paper presented at the AIEE national technical meeting, Salt Lake City, Utah, September 2-4, 1943.

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Information for this paper, some of it unpublished, was supplied by various members of the staff of research laboratories, Westinghouse Electric and Manufacturing Company, particularly, E. A. Davis, A. Nadai, P. R. Toolin, P. G. McVetty, and T. F. Hoogstenberg.

Table I. Physical Constants of Copper

Chemical symbol			Cu
Atomic number			29
Mean atomic weight			63.57
	Atomic Number	Atomic Weight	Abundance
Isotopes	29	63	68
	29	65	32
Melting point (degrees centigrade)			1,083
Boiling point (degrees centigrade)			2,310
Density (grams per cubic centimeter)			8.94
Crystal type			Face-centered cubic
Size of unit cell (centimeters)			3.6077×10^{-8}
Thermal conductivity (watts per square centimeter per centimeter per degree centigrade per centimeter, 20 C)			3.82 at 0 C 3.81 at 20 C 3.72 at 200 C
Electrical resistivity (ohm-centimeters, 20 C)			1.682×10^{-6}
Temperature coefficient of electrical resistivity ohms per ohm per degree centigrade			0.00393
Wiedemann–Franz ratio, 20 C, $\left(\gamma = \frac{k}{\sigma T}\right)$ (See Figure 24)			2.19×10^{-8}
Thermal expansivity (millionths per degree centigrade)			15.89 at 0 C 16.42 at 20 C 18.16 at 200 C
Magnetic susceptibility			-0.085×10^{-6}

Table II. Mechanical Properties of High-Conductivity Oxygen-Free Copper Strip, 0.04-Inch Thick[1]

	Hard	Soft
Tensile strength (pounds per square inch)	50,000–56,000	32,000
Apparent elastic limit (pounds per square inch)	38,000–43,000	3,000
Yield strength 0.5 per cent extension (pounds per square inch)	47,000–55,000	8,000
Yield strength 0.2 per cent offset (pounds per square inch)	47,000–54,000	6,000
Yield strength 0.1 per cent offset (pounds per square inch)	45,000–52,000	6,000
Elongation, per cent in 2 inches	3	43
Hardness, Rockwell *B*, 1/16-inch ball 100-kilogram load	53–59	
Young's modulus of elasticity (pounds per square inch)	16,000,000	

Table III. Mechanical Properties of Aged Copper-Chromium Alloy

	Aged	Aged and Cold-Rolled
Ultimate tensile strength	55,000	64,000
Apparent elastic limit	30,000	50,000
Elongation in 2 inches	30 per cent	15 per cent

of the alloy; that is, the hardening effect per solute atom is then much greater than for the solid-solution condition. At the same time the obstructive effects on current flow are decreased.

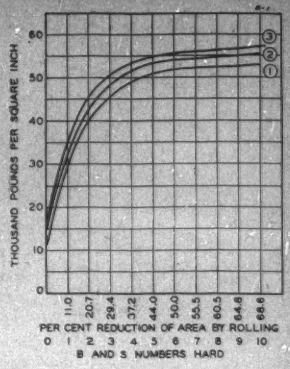
In some cases the net result is a large increase in both mechanical strength and electrical conductivity as compared with those of the quenched alloy. If the precipitation process is carried too far, the crystallites grow, and the special hardening effects associated with their initial extremely minute size disappear. Then they behave merely as so much finely divided foreign material in a plastic matrix. The alloy loses most of its extra hardness and becomes rather uninteresting.

In the electrical field precipitation-hardening effects are displayed to special advantage by copper-chromium and copper-chromium-silver alloys in which the chromium and silver contents may lie in ranges between approximately 0.3–1.0 per cent and 0–0.1 per cent, respectively. The valuable properties of these alloys arise primarily from the chromium, the silver, when used, acting as a useful auxiliary.

Figure 6 shows the effect on electrical conductivity of increasing the amount of chromium in solid solution in copper by quenching a fully precipitated 0.85 per cent

Figure 1. The effect of cold-rolling on the yield strength of oxygen-free copper strip (no residual deoxidant) previously annealed to a grain size of 0.015 millimeter (99.94 per cent copper—0.040-inch stock)

① *0.10 per cent yield strength (offset)*
② *0.20 per cent yield strength (offset)*
③ *0.50 per cent yield strength (extension)*



copper-chromium alloy from various solution temperatures. The decrease in conductivity from 85 to 33 per cent is striking. Quenched from 1,000 degrees centigrade, this alloy would show an apparent elastic limit of less than 5,000 pounds per square inch, and elongation of 45 per cent in two inches, properties comparable to those of annealed pure copper. The results of carrying out the precipitation or "aging" process at 450 degrees centigrade are shown by Figure 7. Both hardness and conductivity rise, and both are still increasing after more than 500 hours at 450 degrees centigrade (842 degrees Fahrenheit). The aged alloy will show approximately the mechanical properties given in Table III. Despite the increase in strength the ductility remains relatively high.

The thermal endurance of the alloy in the hard high-conductivity condition is enormously greater than that of any copper-base solid-solution alloy of comparable strength. Even when cold-working is utilized to enhance the strength of the precipitation-hardened alloy, the thermal endurance remains high.

This and the beneficial effects of a small addition of silver are shown by Figures 8 and 9 which indicate the effects of cold-work and tempering on the hardness of precipitation-hardened copper-chromium and copper-chromium-silver alloys. The relatively low stability of the severely cold-worked material should be noted. This is a general phenomenon. In the copper industry it has long been known that it is difficult to obtain "dead-soft" anneal of lightly cold-worked copper. Similar effects are noticeable in ferrous alloys.

Beryllium-copper alloys exhibit precipitation-hardening effects similar in character to those previously described but of different magnitude. In this case not all the alloying metal (beryllium) can be precipitated. Thus the precipitation-hardening effects are superposed on the solution-hardening effects of the residual beryllium in solid solution (the latter are unusually large for a solid solution) with the result that the tensile properties are higher and the electrical conductivity much lower than for the copper-chromium alloys.

Figures 10 and 11 after Rimbach[4] show the general characteristics of beryllium-copper alloys.

Precipitation-hardening characteristics intermediate between those due to chromium and to beryllium result from the addition of approximately two per cent each of cobalt

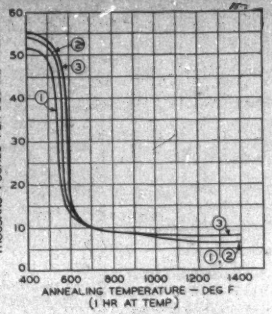


Figure 2. The effect of annealing on the yield strengths of oxygen-free copper strip (no residual deoxidants) previously cold-rolled to number 6, B and S gauge, (50 per cent reduction of area) from a material having a grain size of 0.015 millimeter (99.94 per cent copper—0.040-inch stock)

① *0.10 per cent yield strength (offset)*
② *0.20 per cent yield strength (offset)*
③ *0.50 per cent yield strength (extension)*

and iron to copper. Beryllium in small amounts gives higher hardness and lower conductivity. A general idea of the electrical and mechanical properties of such alloys is given by Figure 12 which shows the hardness and conductivity as related to heat treatment for copper-chromium, copper-iron-cobalt, and copper-iron-cobalt-beryllium alloys.

CREEP AND FATIGUE IN HIGH-STRENGTH HIGH-CONDUCTIVITY ALLOYS

So far attention has been directed to the properties at room temperature as affected by alloying and thermal and mechanical manipulations. The electrical designer is becoming more and more concerned with the behavior at high temperatures of his materials when subject to sustained as well as repeated loading.

Davis[5] has recently published the results of a careful investigation of the creep of oxygen-free high-conductivity copper at various temperatures and over fairly long test periods.

Davis describes the preparation of his material as follows:

"Approximately 60 lengths of oxygen-free high-conductivity copper, each 4 ft. long 0.2 in. diam., were obtained from the Scomet Engineering Company. The rods were packed in a steel channel beam and annealed at 500 C for one hour. About one hour was required for the heating period, and several hours were required for cooling in the furnace. The annealing was done in an atmosphere of nitrogen which had been passed over hot copper chips and activated alumina to remove the moisture and oxygen. The annealed copper appeared fairly clean and had an average Vickers hardness of 49.

"Each bar was prestretched 8 per cent before it was tested.

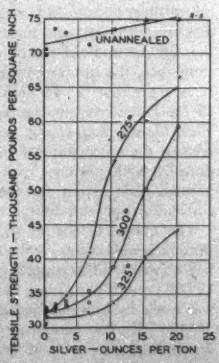


Figure 3. Tensile strength of 24-gauge (0.020-inch) wire annealed for two minutes at temperatures shown

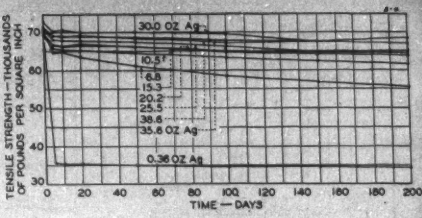


Figure 4. Effect of silver on softening of 16-gauge wires at 150 degrees centigrade

The figures on the curves indicate the number of ounces of silver per ton of copper which the wires contain

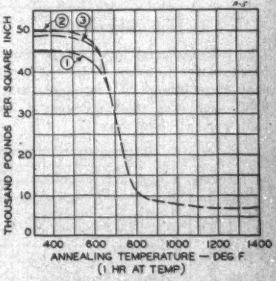


Figure 5. The effect of annealing on the yield strength of tellurium copper rod previously cold-drawn 50 per cent (reduction of area) from material having a grain size of 0.025 millimeter (0.45 per cent tellurium, remainder copper—rod under one inch in diameter)

① *0.10 per cent yield strength (offset)*
② *0.20 per cent yield strength (offset)*
③ *0.50 per cent yield strength (extension)*

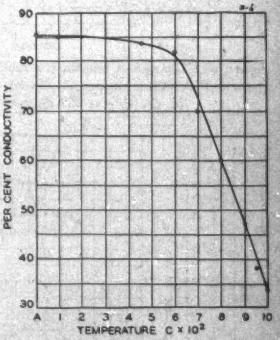


Figure 6. The effect of quenching from various temperatures on the conductivity of a copper-chromium alloy containing 0.83 per cent chromium

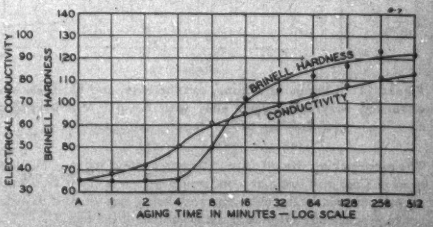


Figure 7. The rise of hardness and conductivity during the first stages of aging of an alloy containing 0.8 per cent chromium (quenching temperature 950 degrees centigrade; aging temperature 450 degrees centigrade)

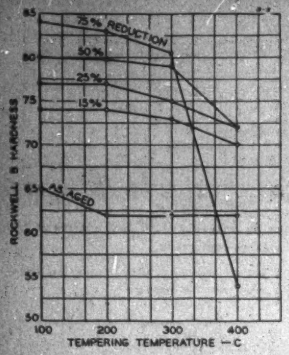


Figure 8. Curves of temperature versus hardness for Cupaloy 3144—0.40 per cent chromium, 0.007 per cent silver, 0.007 per cent silicon—tempered for four days

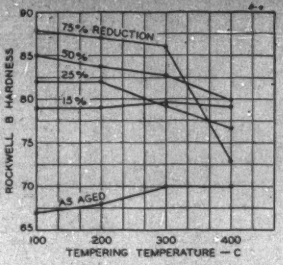


Figure 9. Curves of temperature versus hardness for Cupaloy 3145—0.36 per cent chromium, 0.064 per cent silver, 0.005 per cent silicon—tempered for four days

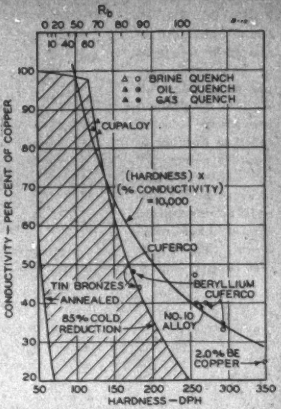


Figure 12 (right). Comparison of precipitation-hardened copper alloys with cold-worked bronzes

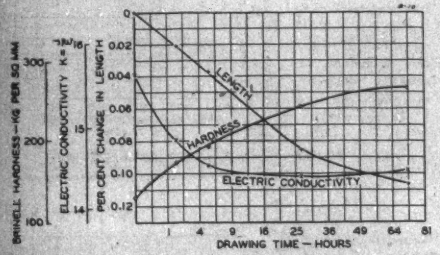


Figure 10. Change in length, conductivity, and hardness of a quenched beryllium-copper alloy with 2.5 per cent beryllium on drawing at 200 degrees centigrade

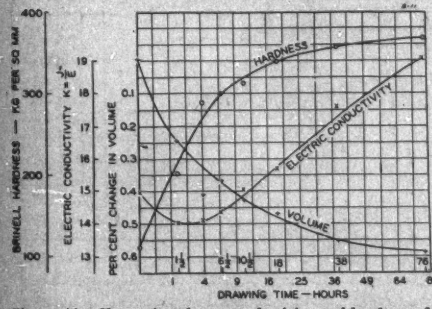


Figure 11. Change in volume, conductivity, and hardness of a quenched beryllium-copper alloy with 2.5 per cent beryllium on drawing at 250 degrees centigrade

The prestretching was all done at the same rate of strain. The true stress at 8 per cent strain at room temperature was about 23,500 psi. All stresses used in the tests were well below this amount in order not to produce large strains at the beginning of the tests."

The high lights of his results are shown by Figures 13 through 15.

From the curves it may be noticed that creep rates increased much more than proportionally with both load and temperature and that slow creep occurred at room temperature at stresses as low as 5,610 pounds per square inch. Relaxation test indicated that at room temperatures the stress would fall from 22,170 to 18,000 pounds per square inch in 1,000 hours and from 4,530 to approximately 4,000 pounds per square inch in like time. Figure 16 shows some more recent unpublished results from Davis which show that small amounts of silver greatly decrease creep rates at 200 degrees centigrade. At 8,330 pounds per square inch and with no detectable silver the minimum creep rate was 9.5×10^{-7} inch per inch per hour. With 0.078 per cent silver the rate at 8,310 pounds per square inch was only 1.4×10^{-7} inch per inch per hour—less than one seventh that for the unalloyed copper. Even at 9,820 pounds per square inch the rate was only 1.5×10^{-7} inch per inch per hour. Thus it appears that silver greatly benefits not only thermal endurance but high-temperature strength as well. Certain test data obtained by McVetty for 0.5 per cent copper-chromium alloy are shown by Table IV.

If we consider the data of Table IV for copper-chromium-silver alloy at 19,000 pounds per square inch and 100 degrees centigrade and make the conservative assumption that all the allowed plastic deformation occurs at a constant rate, the minimum creep rate for that alloy would be no more than 6.5 per cent of that estimated from Figure 15 for Davis' oxygen-free copper under like conditions. That is, one half of one per cent of chromium has increased the creep resistance of copper under those conditions by 1,500 per cent with a loss of conductivity of perhaps as little as ten per cent. Again there seems to be correlation between thermal endurance and creep strength.

The curves of Figure 15 were prepared by Davis to summarize his creep results on high-conductivity oxygen-free copper. The estimate of the minimum creep rate at 19,000 pounds per square inch and 100 degrees centigrade was made by interpolating a curve representing the creep at 100 degrees centigrade between the experimentally determined curves for 80 degrees centigrade and 130 degrees centigrade respectively. This interpolated curve intersected the 19,000 pounds per square inch co-ordinate at a point corresponding to a minimum creep rate of 2×10^{-7} inch per inch per hour. This is 15.3 times the calcu-

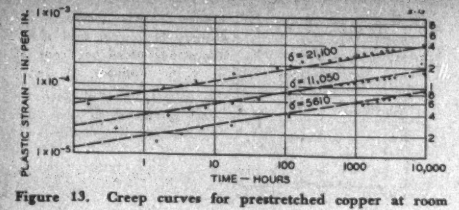


Figure 13. Creep curves for prestretched copper at room temperature

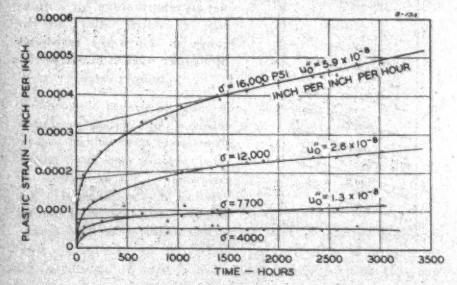


Figure 13A. Creep of oxygen-free copper at 80 degrees centigrade

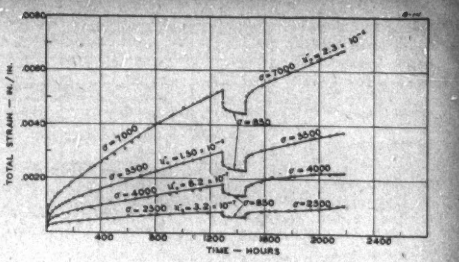


Figure 14. Creep of oxygen-free copper at 235 degrees centigrade

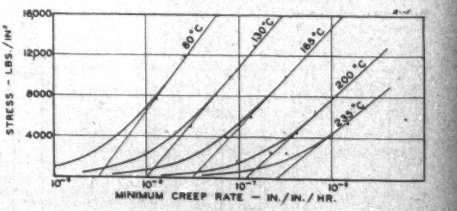


Figure 15. Stress-creep-rate relations for oxygen-free copper

lated uniform creep rate of 1.3×10^{-8} inch per inch per hour for the copper-silver-chromium alloy at 19,000 pounds per square inch and 100 degrees centigrade. The measured minimum creep rate for the copper-chromium-silver alloy was 1.25×10^{-8} inch per inch per hour.

FATIGUE AND ENDURANCE OF COPPER ALLOYS

Brittle fractures sometimes occur in copper parts which by conventional tests show no evidence of subnormal ductility. Such failures are usually the result of "fatigue" under repeated stress resulting from vibration or other cyclic loading. On the whole, the mechanical endurance of metals runs roughly parallel with tensile strength, and, despite its high ductility, soft copper may fail by fatigue at relatively low stress. For tough-pitch copper Wilkins and Bunn give the values of fatigue strength for 10^8 reversals shown in Table V.

Table VI shows data on tough-pitch copper annealed and cold-rolled and on a precipitation-hardened copper-chromium-silver alloy (chromium 0.5 per cent, silver 0.1 per cent).

The age-hardened copper-chromium-silver alloy has double the endurance of the cold-worked copper and approximately 90 per cent of its conductivity.

Figure 17 shows the results of several high-temperature fatigue tests by Toolin on forged heat-treated copper-chromium-silver alloy.

These results indicate that at 260 degrees centigrade (500 degrees Fahrenheit) fatigue strengths of the order of 25,000 pounds per square inch at 10^8 reversals are obtainable. That is a very satisfactory figure and is especially interesting in a high-conductivity alloy.

Toolin's tests were made in bending on round polished bars by means of a 120-cycle per second electrically driven

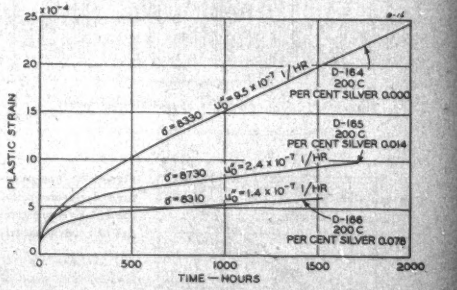


Figure 16. Creep curves for silver copper at 200 degrees centigrade

σ = stress, pounds per square inch
u″ = creep rate, inches per inch

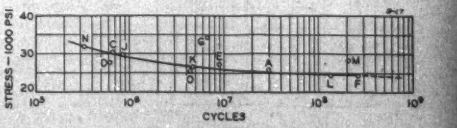


Figure 17. Cupaloy endurance curve at 500 degrees Fahrenheit (260 degrees centigrade)

120-cycle electromagnetic bending fatigue machines
Specimen: 0.505 inch in diameter
Material: forged Cupaloy
Heat treatment: water quench 1,000 degrees centigrade; aged 20 hours at 450 degrees centigrade
Tensile strength: at room temperature, 53,000 pounds per square inch; at 500 degrees Fahrenheit, 35,000 pounds per square inch

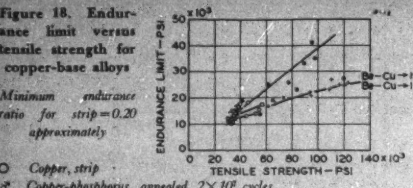


Figure 18. Endurance limit versus tensile strength for copper-base alloys

Minimum endurance ratio for strip = 0.20 approximately

- ○ *Copper, strip*
- ♂ *Copper-phosphorus, annealed, 2×10^8 cycles*
- □ *Copper, arsenical, tough-pitch*
- △ *Gilding metal strip, 10^8 cycles*
- × *Red brass, rod, 10^8 cycles*
- ✚ *Nickel-silver, strip, 10^8 cycles*
- ● *Copper-nickel, rod, 10^8 cycles*
- ⊙ *4 per cent phosphorus bronze, strip*
- ■ *Beryllium-copper strip, 10^8 cycles*
- ◆ *Copper-chromium-silver*

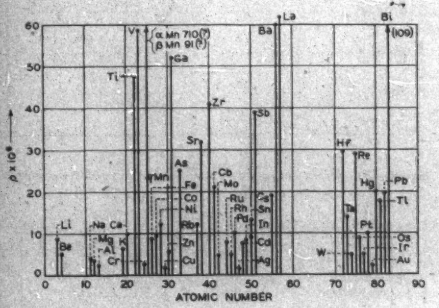


Figure 19. The resistivity of monatomic metals

The ordinates are expressed in ohm-centimeters

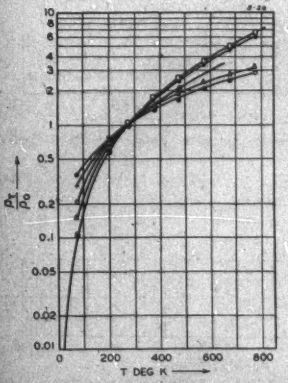


Figure 20. Temperature dependence of the relative resistivities of several metals

The ordinate is the ratio of the resistivity at temperature T to that at zero degrees centigrade

- ● *Iron*
- □ *Nickel*
- ○ *Platinum*
- △ *Copper*
- ✚ *Magnesium*
- ◓ *Bismuth*

testing device. Temperatures and amplitude are controlled automatically, and loading is stopped automatically as soon as fatigue cracks start. Thus the fatigue process can be "caught in the act" and the specimen removed for study before failure has become extensive. The relatively high stress frequency greatly shortens testing time, a point of considerable importance.

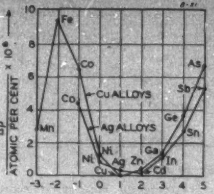


Figure 21. The increase in resistivity of copper and silver alloys per atom per cent of solute

The abscissa is the number of valence electrons of the solute atom relative to the closed d shell

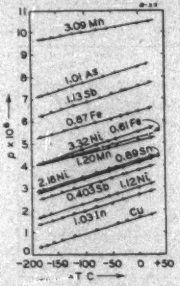


Figure 22. Curves of resistivity versus temperature for a number of copper alloys in the range in which the resistivity of copper varies linearly with temperature

It should be observed that the resistivities of the alloys are much higher than that of copper at low temperatures, implying very large residual resistivities. The resistivities are expressed in ohm-centimeters. The numbers indicate the atomic per cent of the alloying metal (after Linde)

Copper-beryllium alloys properly heat-treated show remarkably high mechanical endurance and for this reason are quite widely used for springs and other parts subject to repeated loading. The electrical conductivity of these alloys as heat-treated is about 30 per cent, quite high enough to be interesting for electromechanical applications. Figure 18 is an arrangement of data from Wilkins and Bunn intended to give some perspective of the relation between tensile properties as ordinarily determined and mechanical endurance for a number of copper alloys.

It seems worth-while to emphasize the fact that the relatively high ductility of copper and copper-base alloys is no guarantee against fatigue failure at notches, inadequate fillets, toolmarks or other points of stress concentration. It is true that the more ductile metals will settle down by localized plastic flow in a way not possible in brittle materials. However, in high-speed apparatus the number of stress cycles rapidly mounts into the millions, and the engineer, designer, and shop should be alert to the little circumstance that might cause a big failure. Mechanical stress is just as pervasive as electrical stress and, especially when oft repeated, can cause failures from pinpoint defects just as certainly as do electrical stresses.

ELECTRICAL AND THERMAL CONDUCTIVITY, TEMPERATURE, AND COMPOSITION

With the exception of silver, copper has the lowest electrical and thermal resistivity of all the elements. Figure 19[7] shows the standing of copper among the metals as to resistivity at ordinary temperatures. It is interesting to note the periodic rise and fall of electrical resistivity with increasing atomic number.

The effect of temperature on the resistivity of copper and a few other metals is shown by Figure 20.[7] Despite their low resistivity, neither copper nor silver becomes a superconductor at low temperatures. Columbium, lead, and zinc are conspicuous because of the relatively high tem-

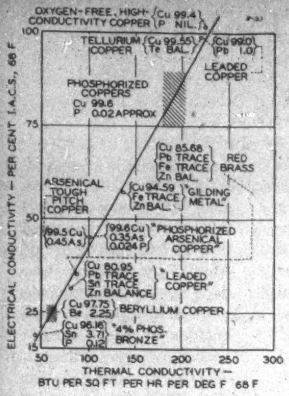


Figure 23. Copper alloys—relation between thermal and electrical conductivity (after Wilkins and Bunn)

peratures at which they show superconductivity, namely 9.22, 7.86, and 7.2 degrees Kelvin, respectively.

Figure 21[7] shows the effects on silver and on copper of small quantities of a number of alloying elements in solid solution. The similarity of the reactions to alloying of silver and copper is striking.

The electrical resistivity of copper containing even small percentages of other metals in solid solution is always higher than that of the pure metal and appears to be composed of two parts: one, apparently characteristic of copper, which is responsive to temperature; and another, due to the presence of the foreign atoms, which is only slightly affected by temperature. These facts are illustrated by Figure 22[9], where it may be seen that the slopes of the various temperature-resistivity curves are approximately the same whatever their level on the resistivity scale.

There is a rule of thumb which states that for most metals and alloys thermal conductivity is proportional to electrical conductivity. How well this holds for a number of copper-base alloys is shown by Figure 23 based on the data of Wilkins and Bunn. That this rule is not a law may be seen from Figure 24, reproduced from Seitz (page 177). Despite the abnormalities of some of the metals, it can be said that the thermal conductivity of the dilute copper-base alloys for most engineering purposes may be taken as proportional to the electrical resistivity. This relation is usually expressed by the Wiedemann-Franz law

$$\gamma = \frac{k}{T\sigma} \qquad (1)$$

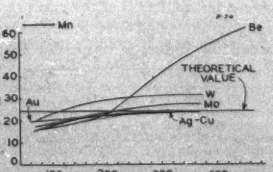


Figure 24. The Wiedemann - Franz ratio for several metals

The ratio r ($r = k/T\sigma$) is given in units in which σ is measured in ohms^{-1} centimeters^{-1}, k is measured in watts degrees^{-1} centimeters^{-1}, and T is the absolute temperature. The theoretical value is 2.45×10^{-8} watt-ohm per degree[2]

Table IV. Comparative Creep Data for Cupaloy and Copper—Estimated Stress for a Service Life of Ten Years

Allowed Total Deformation (Per Cent)	Elastic* Deformation at Rated Stress (Per Cent)		Allowed Plastic Deformation at Rated Stress (Per Cent)		Rated Stress (Pounds Per Square Inch)	
	Cu	Cu-Cr-Ag	Cu	Cu-Cr-Ag	Cu	Cu-Cr-Ag
0.25	0.08	0.13	0.17	0.12	11,800	19,000
0.50	0.097	0.19	0.403	0.31	14,300	27,800
0.75	0.105	0.224	0.645	0.53	15,700	33,400
1.00	0.113	0.250	0.887	0.75	16,800	37,000

* Young's modulus = 14.9×10^6 pounds per square inch.

Table V. Fatigue Strength of Tough-Pitch Electrolytic Copper

Condition	Stress for Failure at 10^8 Reversals (Pounds Per Square Inch)	Tensile Strength (Pounds Per Square Inch)
Soft	11,000	30–35 $\times 10^3$
Hard, 2 *B.* and *S.*	13,000	40–45 $\times 10^3$
Hard, 8 *B.* and *S.*	14,000	55–57 $\times 10^3$

Table VI. Fatigue Strength of Copper and Copper-Chromium-Silver Alloy

Material	Fatigue Strength	Relative Endurance
Copper, annealed	9,500	1.00
Copper, cold-drawn 15 per cent	12,000	1.26
Copper-chromium-silver alloy (chromium 0.5 per cent, silver 0.1 per cent nominal)	21,500	2.25

where T is the absolute temperature, σ is measured in ohms^{-1} centimeters^{-1}, k in watts degrees^{-1} centimeters^{-1} and γ is the Wiedemann-Franz ratio. The theoretical value of $k/T\sigma$ is 2.45 watt-ohms/deg.[2]

Rearranging equation 1 and substituting the numerical value for γ gives

$$\frac{k}{\sigma} = 2.45T$$

That is, the ratio of thermal conductivity to electrical conductivity increases with the absolute temperature. In other words, the temperature coefficient of thermal resistivity is less than that of the electrical resistivity.

In developing this article I have emphasized the effects on copper of elevated temperatures and of small alloy additions, because it has seemed that in those directions lay, respectively, the more pressing engineering problems and the greatest possibilities of satisfactory answers.

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Effect of High-Frequency Fields on Micro-Organisms

HUGH FLEMING

Because of the many vague and conflicting reports on the effect of short waves on micro-organisms, the laboratory analysis reported in this article was undertaken; the author has endeavored to correlate the electrical data with medical and bacteriological data. Because of time and equipment limitations, the study shows trends in electrobiological treatment at high frequencies rather than conclusive evidence.

THE MEDICAL USE of high-frequency fields in producing artificial fevers has been recognized in Europe for 30 years. Medical men in the United States have used short-wave diathermy extensively for the last ten years. The basic pattern of use involves the exposure to a high-frequency field of an ailing portion of the body until the local temperature has been increased considerably. Heat is generated by the passage of eddy currents, hysteresis losses, and dielectric losses. The temporary rise in temperature is advantageous primarily because of the increased activity of disease-fighting components of the blood stream. Undoubtedly secondary effects exist, such as the outright killing of bacterial bodies unable to survive the rapid change of temperature and the rapid reversals of potential.

Two general methods of enveloping the body in the high-frequency field are used. The most common of these is placing the structure to be treated in the dielectric field existing between two small applicator plates. The second method is to cause an inductive circuit to conform to the necessary dimensions so that it completely envelops a body part. Here the magnetic field would play a large part, and hysteresis losses would seem to be large. The Fisher Scientific Company has made extensive tests on the relative heating efficiency of the two methods and has found the inductive method greatly superior.

Originally the value of high-frequency treatment of humans was credited only to the uniform and localized fever effects made possible. More recently, a study of the effects of short waves upon bacteria and other micro-organisms has shown that lethal effects are evidenced without appreciable rise in temperature. Haase and Schliephake reported that no comparison could be made between the temperature of water passing high-frequency currents of lethal value and the temperature of hot water required to produce the same immobilizing action. This makes evident the existence of additional effects of germicidal value.

High-frequency currents between the limits of 9,000 and 100,000 kilocycles are of recognized medical value. Generation is accomplished by means of vacuum-tube oscillators much in the same manner as for radio broadcast purposes. (See circuits in Figures 1 and 2.) In the literature, there are limited reports of attempts to immobilize micro-organisms in water media by the passage of high-frequency currents. Most of the work has been done by European doctors of medicine, with little presentation of what would be termed engineering data.

It can be stated definitely that all forms of microscopic life can be immobilized with short waves if treatment is severe enough. Bacteria, in particular, are said to be immobilized rather than killed because the only determination that can be made is a test of their power of reproduction. Failing to reproduce, bacteria are considered dead. If microscopic examination shows bacteria broken into component parts, it can be assumed that they have been destroyed. However, merely turning on enough power to obtain a lethal effect is not economically sound, and it is reasonable that there should be a search for optimum germicidal conditions.

Nearly all cell life can be speeded up in its rate of growth under the stimulus of high frequency. This action takes place at a progressively faster rate as the power is increased, until a point of overstimulation is reached and lethal effects occur. This point of overstimulation differs widely depending upon the age, virulence, and extent of colonization of the organism under study. A curve illustrating the rate of growth as a function of the power applied is given in Figure 3.

Haase and Schliephake were able to immobilize both streptococci and staphylococci with waves from 3 to 20 meters. Hicks was unable to destroy these same bacteria with 4.5 meter waves. It is interesting to note that he reported his cultures contained salt, which increased the conductivity of the water. Liebesny, using 20- to 30-meter waves, stated at the same time that bacteria were killed in reciprocal proportion to the increase of electrolyte introduced. From his experiments he claimed that the effect on a certain electrolyte is optimum (using a rise in temperature as the standard), when the dielectric properties have a definite mathematical relationship to frequency. He wrote an equa-

Essential substance of a paper, "A Study of the Effect of High-Frequency Fields on Micro-Organisms," which was awarded the AIEE national prize for Branch paper for the academic year ending June 30, 1942. The paper was presented at a joint meeting of the Portland (Oreg.) Section and the Oregon State College Branch, Corvallis, May 16, 1942.

Hugh Fleming was an enrolled student at Oregon State College, Corvallis, when the paper was presented. He is now a student engineer, General Electric Company, Schenectady, N. Y.

The author acknowledges the assistance of the Oregon State College department of bacteriology.

tion for this: $K = f/(cx)$, where f represents frequency, c, the dielectric constant, and x, the reactance.

Schmidt and Hoensdorf found that streptococci and Escherichia coli were materially retarded in their growth in a moderate high-frequency field if localized. They reported good results at 4.6 meters in the presence of physiological salt or boric-acid solutions. Fabian and Graham tested bacillus coli and found that 30 meters with a current of 0.8 ampere produced death. They cautioned against concluding, immediately on the immobilizing of bacteria, that they had been successfully killed as . . . "a seemingly lethal effect may be followed in a few days by a rapid and intensive growth." Tibor de Cholnoky indicates a correlation of media and lethal dosage. He states that water-borne bacteria are more

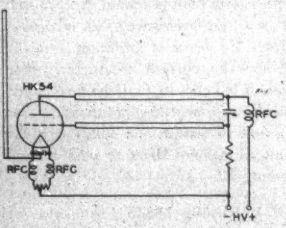

Figure 1. Schematic diagram of a vacuum-tube oscillator for 90-centimeter waves

difficult to immobilize than those in some other media such as air.

Two theories have been proposed explaining the mechanics of rendering a culture of micro-organisms nonviable. The first of these is that the instantaneous temperature of the bacteria, or other life, can be raised to a very high value without necessarily affecting the surrounding media to a great extent. The assumptions are that the hysteresis, eddy current and I^2R losses are very great in the matter making up the cell. If this theory were true exclusively, it would appear that the effectiveness should be proportional to the frequency. As was pointed out already, there is a definite frequency band of optimum value above which the immobilizing effects diminish.

The second theory explaining the lethal action of short waves involves the possibilities of mechanical stresses. Nearly all bacteria have a negative charge. It is believed that a condition of mechanical resonance is reached at certain frequencies that so distorts the organic matter of the micro-organism that it is rendered nonviable. This would imply that the high-frequency field acts powerfully enough upon a bacterium, for instance, to cause it to travel a minute distance first in one direction and then in the reverse direction as the field is changed. These oscillations of the tiny bits of matter might well become so rapid as to exceed the elastic limits of the structure of the organism. Since different types of bacteria have entirely different physical dimensions as well as properties, it follows that the frequency of best destructive power would vary for each different type of cell treated. This is true although the optimum frequency for a given type of single cell life is not as critical as might be supposed. Some microscopic evidence of actual bacterial destruction due to distorted masses has been reported.

The variables studied in the laboratory were: frequency, voltage, current, time, and conductivity of the media containing the micro-organisms. All were studied as a function of the immobilizing power of the high-frequency currents.

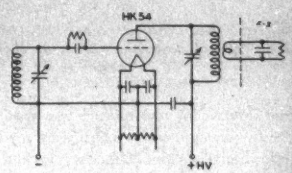

Figure 2. Schematic diagram of a vacuum-tube oscillator for 10–25-meter waves

VARIABLE-FREQUENCY TESTS

In the variable-frequency tests, numerical concentrations of bacteria were maintained as constant as was possible. An attempt was made to keep power outputs constant for all tests by means of flashlight lamps in parallel with a nonresonant line and the loading network. Measurement of light intensity of the lamps was made with a light meter. It is evident that such an arrangement would not measure exactly the output, but would give sufficiently relative values to enable significant data to be taken regarding the remainder of the variables. In all cases, standard six-inch fermentation tubes filled with a total of ten cubic centimeters of media and culture were used. Two oscillators were used. For the range 10–25 meters a tuned-plate tuned-grid Gammatron 54 supplied the power, and below the range of five meters to 90 centimeters a resonant-line oscillator was used. (See Figures 1 and 2.) Utilized power output on all frequencies was approximately ten watts. In no case was a significant rise in temperature permitted. The standard type of bacteria tested were Escherichia coli, which are nonspore-forming vegetative cells found quite commonly in polluted rivers and streams. All tests were made in the electric field existing between two condenser plates.

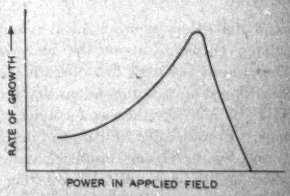

Figure 3. Rate of growth of cell life under stimulus of high frequency

By referring to the curve in Figure 4, it can be seen that all frequencies tested had somewhat of a lethal effect upon the Escherichia coli. This effect became noticeably peaked around 60 megacycles. A standard

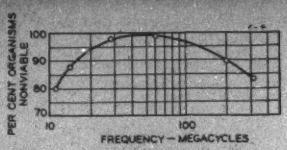

Figure 4. Effect of frequency on Escherichia coli

Samples: 10 cubic centimeters; control: 450,000,000 per cubic centimeter. Maximum temperature: 85 degrees Fahrenheit. Exposure in dielectric field

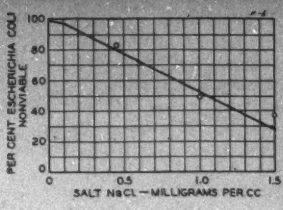

Figure 6. Effect of conductivity upon treatment of Escherichia coli

time interval of one minute was used on all cultures. The frequency measurements were made by means of a radio receiver below 28 megacycles and by Lecher wires above 28 megacycles. Three samples and a control were taken for each of six frequency determinations (350, 200, 60, 28, 14, and 11 megacycles). Each fermentation tube was shaken before exposure to the high-frequency field to distribute the contents evenly and to assure uniform conductivity, and was plated immediately after exposure.

VARIABLE-VOLTAGE AND CURRENT TESTS

The theory holding that hysteresis and eddy-current losses in the high-frequency field raise the instantaneous temperature of a cell to a greater value than the surrounding medium would seem to indicate that the magnetic field plays the important part. On the other hand the theory of mechanical resonance implies that voltage gradients about the bacteria are important. Therefore a resonant line operating on 90 centimeters was devised of such dimensions that a fermentation tube could be placed either at a voltage node or a current node. Considerable unbalance in the oscillator was caused by the former instance, and relative values of power had to be supplied by adjusting the oscillator to a specific increase of plate-power input. For the tuning operations, sample tubes of Escherichia coli had to be used to simulate the anticipated load. Test conditions again involved a standard time interval of one minute and a wave length of 90 centimeters. From the following data it is evident that a large voltage gradient across the bacteria is more important than a high current or an intense magnetic field:

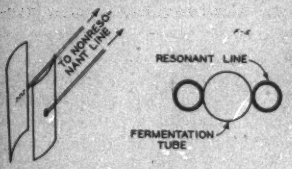

Figure 5. Arrangements for (left) passing a high current and (right) obtaining large voltage gradients

Sample	Average Count Per Cubic Centimeter
Control	450,000,000
High-current treatment	200,000,000
Voltage stressed	1,000,000

In two of the tests, the tubes of Escherichia coli were completely sterilized. The fermentation tubes filled with Escherichia coli acted very much like a portion of the resonant circuit. In one case a high current at a low potential drop made the tubes appear as a conductance, and in the other case a high potential drop caused the tubes to appear as a high resistance. An error was undoubtedly introduced by virtue of radiation from the large fins required for the current treatment. (See Figure 5.) However, it is believed that the tests made are sufficient evidence to support the generalization that obtaining voltage gradients within the solution is far more important than adjustment so as to pass a large radio-frequency current.

TIME-VARIABLE TESTS

All experiments with the element of time as a variable were made with constant-current values as indicated by a light meter and flashlight lamps as in the variable frequency tests previously considered. The power used was approximately ten watts. Standard six-inch fermentation tubes filled with ten cubic centimeters of Escherichia coli and media were used. During the first fraction of a minute almost all the bacteria are rendered nonviable. For the next few minutes, until the solution is completely sterilized, the lethal action appears to go on at a progressively slower rate. Thus, the instantaneous killing power might be written as a reciprocal function $y=1/t^2$, where t represents time. This is in accord with a cluster theory of bacteria which indicates that colonies become more numerous as smaller groups are considered. The larger colonies, while representing a small percentage of the total, present a different mechanical and electrical characteristic, and reduce the effectiveness of the high frequency treatment. The difference in numbers of the bacteria making up a colony as well as their individual size could explain very well the lack of a definite optimum frequency for treatment.

CONDUCTIVITY-VARIABLE TESTS

The question of the effect of variations in conductivity of the medium containing the bacteria to be tested could be approached a number of ways. Variation in the number of bacteria per cubic centimeter causes variation in the conductivity. The type of media in which they were grown may contain varying amounts of salt. In addition, electrolytes such as sodium chloride or boric acid may be added in appreciable quantities without harm to the Escherichia coli used.

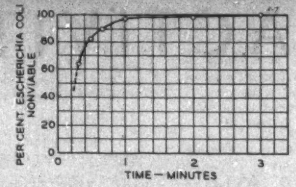

Figure 7. Time of treatment of Escherichia coli

Samples: 10 cubic centimeters; control: 500,000,000 per cubic centimeter. Maximum temperature variation per sample: 70 to 110 degrees Fahrenheit. Exposure in dielectric field. Frequency: 28 megacycles

The latter method was used to demonstrate the effect of varying conductivity upon the immobilizing power of the high frequency. A frequency of 28 megacycles was used with an approximate power of ten watts. The dielectric field was used, and three concentrations of salt were added, (0.5, 1.0 and 1.5 milligrams per cubic centimeter). See Figure 6. The time of treatment was one minute.

The effects were evident at once. A higher concentration of electrolyte decreased the effectiveness of treatment. Again it appeared that high currents, although they generated heat more rapidly, would not give the results that a high-voltage stress would when conductivity and current were lowered.

CONCLUSIONS

It should be emphasized again that the experimental work was only developed to demonstrate trends in the immobilizing effect of the variables listed. Exact measurement of the actual energy dissipated within the fermentation tubes could not be made. Particularly was this true at the ultrahigh frequencies where the percentage of radiated power was appreciable.

The study undertaken showed that germicidal results were easy to obtain even with small amounts of power, and suggests that for some applications a consideration of sterilization by means of exposure to high-frequency fields is warranted economically. Also the possibilities of greatly speeding up life processes such as in yeast manufacture are evident. The best frequency to use for treating a given micro-organism depends upon the size of that organism. However, the bactericidal range can be roughly assigned to the 1–20 meter band.

It is possible that additional lethal effects might be experienced in the ultrahigh frequency range, but control is difficult when it comes to treating large masses of organic matter.

It is evident that a high potential gradient should be maintained for maximum effectiveness. This means that as little electrolyte as possible should be allowed in the presence of the high-frequency field. A high voltage necessitates a tuned circuit whose dimensions conform to the quantity to be treated.

The results of the time study suggest that it would be much more economical to use a large amount of power for a short time than a small amount of power for a long time. If sufficient power is used to immobilize the largest cluster of bacteria in a short interval of time, it appears that the remainder would be easily disposed of.

Toward the close of the experimentation a new technique in testing the effects of high frequency upon bacteria was devised which greatly speeded up the analysis. The method is suggested for further study and outlined as follows: The bacteria to be tested are plated out in countable concentrations on a number of petri dishes. Wires can be imbedded in the agar solutions used so as to remain fixed in the gelatinous mass. Controlled amounts of energy are then applied to the petri dishes and a direct count can be made of colonies the next day. A variation of this consists of omitting the wires and substituting two metal plates on the top and bottom of the petri dishes, arranged to conform to the latters' dimensions.

Figure 8. The 90-centimeter oscillator with the concentric line which coupled the radio-frequency energy to the specimens under test

The upright test tube is between two semicircular aluminum plates insulated by means of polystyrene spacers from a coil form. A parallel flashlight lamp is at the end of the concentric line at the left. This was used to maintain relative values of current in conjunction with a light meter as explained in the text

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INSTITUTE ACTIVITIES

Program Announced for Winter Technical Meeting, January 24–28, 1944

A program of 30 technical sessions and conferences, including a general session, has been arranged for the AIEE winter technical meeting to be held in New York, N. Y., January 24–28, 1943. Headquarters for the meeting will be in the Engineering Societies Building. In accordance with the wartime policy adopted by the board of directors, preference has been given to papers which are of aid in the war effort.

The winter technical meeting of the Institute of Radio Engineers will be held in the Hotel Commodore, January 28–29. The programs for the two meetings have been co-ordinated, with the AIEE communication and electronics session scheduled for Thursday afternoon, and a joint IRE–AIEE session Thursday evening, so as to provide three days of continuous interest for radio and communication engineers. The IRE annual business meeting, followed by a session of technical papers, will be held Friday morning. In the afternoon a symposium on work of the Radio Technical Planning Board will be held, followed by a session of technical papers. Awards will be presented at a banquet that evening, and there will be an annual address by the retiring president, L. P. Wheeler. Saturday morning a symposium of papers will be held, followed by a technical session in the afternoon.

JOINT IRE–AIEE SESSION

The principal speaker at the joint IRE–AIEE session, which will be held in the Engineering Auditorium on the evening of January 27, will be Major General Roger B. Colton, chief, engineering and technical service, Signal Corps, United States Army. The address will be on the subject of "Enemy Army Communications Equipment." Phases of the subject to be discussed by General Colton include the importance of communications in today's war with its speed of movement and the great distances involved, intelligence, how captured equipment is obtained and what is done with it, as well as a general statement of what has been found out about enemy equipment and what we have found out in the laboratories. Specific examples of equipment will be given, and general and specific comparisons will be made with the United States equipment. In conclusion, General Colton will specify some particular problem and explain how electrical and radio engineers can help in the solution of problems. After the address a display of communications equipment and photographs of captured equipment will be shown.

GENERAL SESSION

The Edison Medal will be presented to Vannevar Bush at the general session Wednesday morning, January 26. Doctor Bush was awarded the medal "for his contribution to the advancement of electrical engineering, particularly through the development of new applications of mathematics to engineering problems, and for his eminent service to the Nation in guiding the war-research program."

At the conclusion of the medal presentation ceremonies there will be a featured talk on a topic of interest to many members.

SMOKER

In order that those attending the winter technical meeting may have an opportunity to get together with their friends under conditions where all may relax and pass a thoroughly enjoyable evening it has been decided this year to have a "smoker," Tuesday evening, January 25, at the Hotel Commodore. Insofar as possible all conditions surrounding the popular affairs of previous years will be provided. Ticket, including dinner and show, will be five dollars per person. Tables for ten can be reserved by advance payment. Checks should be made out to "Special Account, National Secretary, AIEE."

THEATER TICKETS

As an accommodation to our out-of-town members attending the meeting, a limited number of theater tickets to popular shows will be available for purchase. Preference will be given to out-of-town orders. All tickets will be for Wednesday evening, January 26, not the 27th, as previously announced. Orders must be accompanied by checks made out to "Special Account, National Secretary, AIEE." If acceptable, an alternate selection should be named. Tickets at $4.40 each for the following shows have been reserved:

1. "One Touch of Venus"
2. "Winged Victory"
3. "Ziegfeld Follies"

Members will be advised of the disposition of their orders, and tickets will be held at AIEE headquarters.

PATENT EXHIBITION

A catalog of some 45,000 United States patents and patent applications in the mechanical, electrical, and chemical fields, formerly enemy-owned or enemy-controlled will be on exhibit during the meeting. These patents and patent applications are available for licensing under liberal terms, and Leo T. Crowley, Alien Property Custodian of the United States Government, under whose authority they are being shown, hopes that American engineers will realize the full potentialities of the inventions covered by these vested patents and patent applications by employing them in the war effort wherever possible and developing them for the postwar period.

A member of the Custodian's staff will be present to answer questions.

REGISTRATION AND HOTELS

Members who have received an advance registration card by mail should fill in and return the card promptly. Upon arrival at the meeting members who registered in advance should not fill in another card, but badges should be obtained. A registration

Schedule of Events

Monday, January 24

9:30 a.m.	Transmission and distribution
9:30 a.m.	Electrical measuring instruments
9:30 a.m.	Conference on electric welding
2:00 p.m.	Power generation, transmission, and distribution
2:00 p.m.	Applications of electrical measurements and basic sciences
2:00 p.m.	Conference on marine transportation

Tuesday, January 25

9:30 a.m.	Transmission and protective devices
9:30 a.m.	Conference on turbogenerator characteristics
9:30 a.m.	Conference on measurement of temperature rise in continuous-duty machines
2:00 p.m.	Circuit breakers
2:00 p.m.	Land transportation
2:00 p.m.	Conference on permissible temperature of short-time rated machines
2:00 p.m.	Conference on speed relaying
6:30 p.m.	Smoker at the Hotel Commodore

Wednesday, January 26

10:00 a.m.	General session—Edison Medal presentation and feature talk
2:00 p.m.	Conference on lighting
2:00 p.m.	Relays
2:00 p.m.	Conference on industrial control
2:00 p.m.	Conference on civic affairs and co-operation with other organizations
2:00 p.m.	Meeting of safety committee

Thursday, January 27

9:30 a.m.	Air transportation
9:30 a.m.	Conference on domestic and commercial applications
9:30 a.m.	Conference on industrial power applications
2:00 p.m.	Air transportation
2:00 p.m.	Communication and electronics
2:00 p.m.	Industrial power applications
8:00 p.m.	Joint IRE–AIEE session

Friday, January 28

9:30 a.m.	Electrical machinery
9:30 a.m.	Conference on automatic stations
10:30 a.m.	*IRE annual business meeting and technical-papers session
2:00 p.m.	Transformers
2:00 p.m.	Conference on administrative problems in Army and Navy Specialized Training Programs
2:30 p.m.	*IRE symposium on work of the Radio Technical Planning Board
4:30 p.m.	*IRE technical-papers session
7:00 p.m.	*IRE banquet (informal)
8:15 p.m.	Teaching aids for Navy Specialized Training Programs

Saturday, January 29

9:30 a.m.	Special lecture at, and inspection trip through, the Brooklyn Navy Yard—open only to a specially selected and invited teaching personnel
10:00 a.m.	*IRE symposium of papers
2:30 p.m.	*IRE technical session

* All IRE sessions at the Hotel Commodore, except the joint IRE–AIEE session, which will be held in the Engineering Auditorium.

Tentative Winter Technical Meeting Program

Monday, January 24

9:30 a.m. Transmission and Distribution

44-53. Current Rating of Cables As Affected by Mutual Heating in Air or Conduit. IPCEA committee on research

44-54. Calculation of Unbalanced Voltage Drops in Distribution Circuits With Particular Reference to Multigrounded Neutrals. W. R. Bullard, H. L. Lowe, H. W. Wahlquist, Ebasco Services, Inc.

44-10. Transformer Magnetizing Inrush Currents and Influence on System Operation. L. F. Blume, G. Camilli, S. B. Farnham, H. A. Peterson, General Electric Company

44-62. Costs Study of 69- to 345-Kv Overhead Power-Transmission Systems. John G. Holm, Boston Port of Embarkation

9:30 a.m. Electrical Measuring Instruments

44-21. A Multiplied-Deflection A-C Potentiometer. R. B. Marshall, Purdue University

44-4. An Instrument for the Measurement of Large Alternating Currents. Walther Richter, Allis-Chalmers Manufacturing Company

44-33. Crossed-Coil Power-Factor Meters. N. P. Millar, General Electric Company

44-31. Influence of Improved Magnetic Alloys on Design Trends of Electrical Instruments. M. S. Wilson, J. M. Whittenton, General Electric Company

9:30 a.m. Conference on Electric Welding

2:00 p.m. Power Generation, Transmission, and Distribution

44-15. Regulation of A-C Generators With Suddenly Applied Loads. E. L. Harder, R. C. Cheek, Westinghouse Electric and Manufacturing Company

44-12. Steady-State Stability of Synchronous Machines as Affected by Voltage-Regulator Characteristics. C. Concordia, General Electric Company

44-17. Lightning Protection for Rotating Machines. G. D. McCann, E. Beck, L. A. Finzi, Westinghouse Electric and Manufacturing Company

44-23. The Effect of Kilovar Supply on the Design of Systems for Load Growth. T. W. Schroeder, J. W. Butler, N. H. Meyers, General Electric Company

2:00 p.m. Applications of Electrical Measurements and Basic Sciences

44-55. The Accuracy of Measurements in Lumped *R-C* Cable Circuits as Used in the Study of Transient Heat Flow. Victor Paschkis, Michael P. Heisler, Columbia University

44-9. Polarized Light Servosystem. T. M. Beffy, General Electric Company

44-16. A New Differential Analyzer. H. P. Kuehni, H. A. Peterson, General Electric Company

44-24. Symmetrical-Components Analysis of the Four-Phase System. A. Boyajian, General Electric Company

44-45. Some Aspects of Inductance When Iron Is Present. L. T. Rader, E. C. Litscher, General Electric Company

2:00 p.m. Conference on Marine Transportation

Tuesday, January 25

9:30 a.m. Transmission and Protective Devices

44-13. Transmission and Relaying Problems on the Fort Peck Project. Erik Floer, Harza Engineering Company; H. N. Muller, S. L. Goldsborough, Westinghouse Electric and Manufacturing Company

44-52. Fusing Practices on Distribution Systems. John S. Parsons, J. M. Wallace, Westinghouse Electric and Manufacturing Company

● PAMPHLET reproductions of authors' manuscripts of the numbered papers listed in the program may be obtained as noted in the following paragraphs.

● ABSTRACTS of most papers appear on pages 25–31 of this issue and pages 545–7 of the December 1943 issue.

● PRICES and instructions for procuring advance copies of these papers accompany the abstracts. Mail orders are advisable, particularly from out-of-town members, as an adequate supply of each paper at the meeting cannot be assured. Only numbered papers are available in pamphlet form.

● COUPON books in $5 denominations are available for those who may wish this convenient form of remittance.

● THE PAPERS regularly approved by the technical program committee ultimately will be published in "Transactions;" many will appear in "Electrical Engineering."

44-30. Reclosing of Single Tie Lines Between Systems. W. W. Parker, H. A. Travers, Westinghouse Electric and Manufacturing Company

44-50. An Eight-Year Investigation of Lightning Currents and Preventive-Lightning Protection on a Transmission System. E. Hansson, S. K. Waldorf, Pennsylvania Water and Power Company

9:30 a.m. Conference on Turbogenerator Characteristics

This conference is sponsored by the committee on power generation and the Standards committee to develop information that is required in the standardization of turbogenerator characteristics. This is being carried on by the AIEE–ASME Joint Committee on Turbogenerators. The committee is concerned with units of 10,000-kw capacity and above but at present is confining its work to 3,600-rpm units for which the ASME group has recommended 12,500, 20,000, 30,000, 40,000, and 60,000-kw ratings. The conference will include results of a survey of present-day practice in loading and the power-factor rating of generators and also the effect of changing of generator characteristics, such a power-factor rating, short-circuit ratio, temperature rise, on the weight of active material required in the generators. While a part of the conference material will be presented by the AIEE group of the turbogenerator committee, a major portion of the conference time will be available for general discussion, and it is hoped that as many members will participate as possible.

9:30 p.m. Conference on Measurement of Temperature Rise in Continuous-Duty Machines

2:00 p.m. Circuit Breakers

44-44. The Geometry of Arc Interruption—II. Current Zero Phenomena. E. W. Boehne, General Electric Company

44-56. A 500,000-Kva 7.5-Kv Air Circuit Breaker for Steel-Mill Service. R. C. Dickinson, Westinghouse Electric and Manufacturing Company

44-37. High-Voltage Oil Circuit Breakers for Rapid Reclosing Duty. A. W. Hill, W. M. Leeds, Westinghouse Electric and Manufacturing Company

44-47. A Magnetic-Type Air Circuit Breaker for 15,000-Volt Services. L. J. Linde, B. W. Wyman, General Electric Company

44-48. A New Three-Element Current-Limiting Power Fuse. H. L. Rawlins, H. H. Yahnoe, Westinghouse Electric and Manufacturing Company

2:00 p.m. Land Transportation

44-20. Electrification of Large Open-Pit Copper Mines. L. W. Birch, Ohio Brass Company

44-28. Modern Electric Locomotives in Open-Pit Mine Haulage. J. E. Borland, L. G. Riley, Westinghouse Electric and Manufacturing Company

"Open-Pit Copper Mining," a motion picture, by courtesy of the General Electric Company

44-25. Design Features of Generators for Diesel-Electric Switcher Locomotives. C. A. Atwell, Westinghouse Electric and Manufacturing Company

44-27. Diesel-Electric Switching-Locomotive Application by Means of Nomographic Charts. A. P. Millan, T. F. Perkinson, General Electric Company

44-26. Gear Ratio and Its Effect on Traction Motors. G. M. Woods, Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference on Permissible Temperature Rise of Short-Time Rated Machines

2:00 p.m. Conference on Speed Relaying

CP.* Effect of Relaying Time on Damage to Equipment and Lines. H. R. Passon, Philadelphia Electric Company

CP.* Effect of Speed of Relaying on System Stability. E. C. R. Schulze, Public Service Electric and Gas Company

CP.* Influence of High-Speed Relaying and Reclosing on Over-All System Performance. C. E. Parks, Public Service Company of Indiana

6:30 p.m. Smoker at the Hotel Commodore

Wednesday, January 26

10:00 a.m. General Session

Presentation of Edison Medal to Vannevar Bush

Feature talk on a timely topic to be of interest to many members

2:00 p.m. Conference on Lighting

Address: "Progress in Lighting." Preston S. Millar, Electrical Testing Laboratories

Address: "Seeing Things," illustrated by motion pictures. S. G. Hibben, Westinghouse Electric and Manufacturing Company

2:00 p.m. Relays

44-46. The MHO-Carrier Relaying Scheme. E. E. Cordray, A. R. vanC. Warrington, General Electric Company

44-51. The Functions of Ground Preference in Carrier-Current Relay Schemes. S. C. Eyland, S. L. Goldsborough, Westinghouse Electric and Manufacturing Company

44-68. System Voltages and Fault Currents Determined Easily on D-C Board. C. E. Asbury, Illinois Iowa Power Company

44-34. A Versatile Power-Line Carrier System. H. W. Lessner, J. B. Singel, Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference on Industrial Control

44-18. Inverter Action on Reversing of Thyratron Motor Control. H. L. Palmer, H. H. Leigh, General Electric Company

2:00 p.m. Conference on Civic Affairs and Co-operation with Other Organizations

*CP: Conference paper; no advance copies are available; not intended for publication in *Transactions*.

Tentative National Technical Meeting Program (Continued)

2:00 p.m. Meeting of Safety Committee

44-22. Study of Artificial Respiration on Anesthetized Men. **W. B. Kouwenhoven, D. R. Hooker, J. A. York,** The Johns Hopkins University

Thursday, January 27

9:30 a.m. Air Transportation

44-32. Present D-C Aircraft Electric-Supply Systems. **H. C. Anderson, Jr., S. B. Crary, N. R. Schultz,** General Electric Company

44-38. Electric-Circuit Fault-Protective Principles as Applied to D-C Aircraft Systems. **R. H. Kaufmann,** General Electric Company

44-36. Basic Considerations in Selection of Electric Systems for Large Aircraft. **W. K. Boice, L. G. Levoy, Jr.,** General Electric Company

44-43. Testing Aircraft Generators. **H. E. Knoop,** Westinghouse Electric and Manufacturing Company

44-7. Electric Circuits and the Magnetic Compass. **R. C. Burt, H. R. Beck,** Lockheed Aircraft Corporation. Presentation by title

9:30 a.m. Conference on Domestic and Commercial Applications

44-69. The Vibration of Electrical Contacts. **M. N. Russell, Saul Kellien,** Pass and Seymour, Inc. 15 cents by mail.

CP.* Design Procedure for Low-Temperature Panel-Space Heating. **B. F. Raber, F. W. Hutchinson,** University of California

CP.* Data on Electric Loads of Wartime Projects. **O. R. Falls, Jr.,** General Electric Company

CP.* Resistance Wire. **W. A. Gatwood,** Hoskins Manufacturing Company

CP.* Low-Reactance Busway. **J. G. Jackson,** Square D Company

CP.* Protective Devices. Stephen Jones, Heinemann Circuit-Breaker Company

9:30 a.m. Conference on Industrial Power Applications

44-18. Inverter Action on Reversing of Thyratron Motor Control. **H. L. Palmer, H. H. Leigh,** General Electric Company

CP.* Experience With Short Circuits and Breakers, With Emphasis on Co-ordination Between Fuses and Breakers. **L. C. Peterman,** Ford, Bacon, and Davis

CP.* Lightning Protection for Industrial Equipment Operating at Line Potential. **A. C. Muir,** Berwind-White Coal Mining Company

CP.* Plant Distribution Systems. **C. E. Smith,** New York Shipbuilding Corporation

CP.* Dodge Chicago Plant's Distribution Scheme With Airplane-Engine Power-Recovery Circuits. **E. L. Bailey,** Chrysler Corporation

CP.* Induction-Heating Application. **H. E. Somes,** Budd Induction Heating, Inc.

2:00 p.m. Air Transportation

44-57. Effect of Altitude on Electric Breakdown and Flashover of Aircraft Insulation. **L. J. Berberich, G. L. Moses, A. M. Stiles, C. G. Veinott,** Westinghouse Electric and Manufacturing Company

44-58. Electric-Circuit Burning-Clear and Damage Phenomena on Aircraft Structures. **C. M. Foust, J. G. Hutton,** General Electric Company

44-29. Potential Breakdown of Small Gaps Under Simulated High-Altitude Conditions. **M. J. Delorso,** General Electric Company

44-59. Corona in Aircraft Electric Systems as a Function of Altitude. **W. R. Wilson,** General Electric Company

44-5. Aircraft Signal Systems. **Raymond A. Rugge,** Curtiss-Wright Corporation

44-70. Electrically Driven Gyroscopes for Aircraft. **H. M. Witherow, Albert Hansen, Jr.,** General Electric Company

2:00 p.m. Communication and Electronics

44-42. Crossbar Toll-Switching System. **L. G. Abraham, A. J. Busch, F. F. Shipley,** Bell Telephone Laboratories, Inc.

44-49. Automatic Ticketing of Telephone Calls. **O. A. Friend,** Bell Telephone Laboratories, Inc.

44-14. A Short-Cut Method of Estimating TIF of Power Systems With Rectifier Load. **C. W. Frick,** General Electric Company

44-41. Rectifier Circuit Duty. **C. C. Herskind,** General Electric Company

44-8. Electronically Controlled Dry-Disk Rectifier. **Allen Rosenstein, H. N. Barnett,** Signal Engineering Products Company

2:00 p.m. Industrial Power Applications

44-19. A New Electric Hoist Drive for Cranes. **M. A. Whiting,** General Electric Company

44-60. Heating of Nonmagnetic Electrical Conductors by Magnetic Induction—Longitudinal Flux. **R. M. Baker,** Westinghouse Electric and Manufacturing Company

44-39. Supervisory Control for the World's Most Modern Steel Mill. **P. B. Garrett, M. E. Reagan,** Westinghouse Electric and Manufacturing Company

44-61. Electrical Equipment for the War-Emergency Pipe-Line Projects. **K. E. Thomas, W. G. Taylor,** General Electric Company; **Oscar Wolfe,** War Emergency Pipelines, Inc.

44-40. The Capacitor—An Aid to Electric-Power Service for Pipe Lines. **M. A. Hyde, R. E. Marbury,** Westinghouse Electric and Manufacturing Company. "Oil for War," a colored motion picture, by courtesy of the Barrett division, Allied Chemical and Dye Corporation

8:00 p.m. Joint IRE-AIEE Session

Address: "Enemy Army Communications Equipment." **Major General Roger B. Colton,** Signal Corps, United States Army. Captured equipment will be on display at the conclusion of the address.

Friday, January 28

9:30 a.m. Electrical Machinery

44-35. The Asymmetrical Stator as a Means of Starting Single-Phase Induction Motors. **John L. Baum,** Chillicothe, Ohio

44-1. Design of Starting Windings for Split-Phase Motors. **T. C. Lloyd,** Robbins and Myers, Inc.; **J. H. Karr,** Purdue University

44-2. Some Aspects of Electric-Motor Design—Polyphase-Induction-Motor Design to Meet Fixed Specifications. **T. C. Lloyd,** Robbins and Myers, Inc.

44-63. A Design Method for D-C Machines. **M. I. Beers,** Robbins and Myers, Inc.; **J. H. Karr,** Purdue University

44-64. Starting Windings for Single-Phase Induction Motors. **C. G. Veinott,** Westinghouse Electric and Manufacturing Company

9:30 a.m. Conference on Automatic Stations

2:00 p.m. Transformers

44-6. Asymmetrical Loading of Three-Phase Three-Winding Transformer Banks. **P. K. Denissov,** Academy of Science of the USSR

44-65. Thermal Protection of Transformers Under Overload Conditions. **V. M. Montsinger, G. Camilli,** General Electric Company

44-66. Overloading of Transformers—Cases Not Covered by the General Rules. **W. C. Sealey, J. B. Hodrum,** Allis-Chalmers Manufacturing Company

44-67. Effect of Altitude on Impulse and 60-Cycle Strength of Electrical Apparatus. **P. L. Bellaschi, Paul Evans, Jr.,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference on Administrative Problems in Army and Navy Specialised Training Programs

44-3. Cultural Training of the Engineer. **A. Boyajian,** General Electric Company

8:15 p.m. Teaching Aids for Navy Specialized Training Programs

Address: "Electricity on Shipboard." **Captain H. G. Rickover,** Bureau of Ships, United States Navy

Saturday, January 29

9:30 a.m. Special Lecture at, and Inspection Trip Through, the Brooklyn Navy Yard

Under the direction of Captain H. G. Rickover, and open only to a specially selected and invited teaching personnel from the colleges in which Navy Specialized Training Programs are conducted.

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fee of two dollars will be charged to all nonmembers except Enrolled Students and the immediate families of members.

Hotel reservations should be made by writing directly to the hotel preferred.

COMMITTEE

The personnel of the 1944 winter technical meeting committee, which is making the arrangements, is as follows: J. F. Fairman, *chairman;* W. J. Barrett, F. A. Cowan, J. L. Callahan, M. D. Hooven, C. R. Jones, R. A. Jones, F. V. Magalhaes, C. S. Purnell.

NATIONAL ....

Smaller Trim Size for "Electrical Engineering"

To maintain the technical content of *Electrical Engineering* at a high level and still comply with governmental restrictions on the use of paper, the trim size has been reduced to 8¼ by 11¼ inches, effective with this issue. The dimensions of the type page are being maintained essentially as before so that the net result is a more efficient use of paper through reduced page margins. In fact, minor changes were required in the feature-article and news sections to adapt those pages to the new size, which increase the amount of material per page.

The majority of technical society and trade publications adopted this smaller size during 1943 in order to effect the required reduction in paper usage in that year (ten per cent less than in 1942). *Electrical Engineering* could not do this without inconvenience to

the *Transactions* subscribers, however, because sheets for the annual *Transactions* volumes are printed month by month while the monthly sections are on the press, and if a change had been made during the year the result would have been two different-sized pages in the 1943 *Transactions* volume.

In addition to the smaller trim size, lighterweight paper for both the text pages and the covers is being used as the present supply becomes exhausted. These two changes will enable *Electrical Engineering* to carry in 1944 practically the same content as in 1943, unless further restrictions on the use of paper become necessary later in the year. Present usage is limited to 75 per cent of the tonnage used in 1942. Whether or not a further curtailment will become necessary is said to depend on the results of the present intensive conservation and salvage campaign (see page 34).

AIEE Nominating Committee for 1943–44 Announced

The national nominating committee of the AIEE, in accordance with the Institute's bylaws, will meet during the winter technical meeting January 24–28, 1944, in New York, N. Y., to nominate candidates for national officers to be voted on by the membership in the spring of 1944. Members of the national nominating committee are as follows:

Representing the board of directors

C. M. Laffoon, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

T. G. LeClair, Commonwealth Edison Company, Chicago, Ill.

K. B. McEachron, General Electric Company, Pittsfield, Mass.

E. W. Schilling, Montana State College, Bozeman, Mont.

W. R. Smith, Public Service Electric and Gas Company, Newark, N. J.

Alternate:

H. S. Osborne, American Telephone and Telegraph Company, New York, N. Y.

Representing the ten geographical Districts

1. Everett S. Lee, General Electric Company, Schenectady, N. Y.

2. R. C. Gorham, University of Pittsburgh, Pittsburgh, Pa.

3. C. S. Purnell, Westinghouse Electric and Manufacturing Company, New York, N. Y.

4. J. Elmer Housley, Aluminum Company of America, Alcoa, Tenn.

5. J. A. Northcott, Jr., University of Notre Dame, Notre Dame, Ind.

6. Arthur L. Jones, General Electric Company, Denver, Colo.

7. C. H. Kraft, Union Electric Company of Missouri, St. Louis, Mo.

8. B. L. Robertson, University of California, Berkeley, Calif.

9. Orin A. Demuth, Bonneville Power Administration, Portland, Oreg.

10. A. H. Frampton, Hydro-Electric Power Commission of Ontario, Toronto, Ont., Canada

Alternates:

4. J. R. Smith, Louisville Gas & Electric Company, Louisville, Ky.

6. Lawrence M. Robertson, Public Service Company of Colorado, Denver, Colo.

7. F. A. Cooper, Southwestern Bell Telephone Company, St. Louis, Mo.

DISTRICT • • • • •

Great Lakes District Executive Committee Meets

The executive committee of the Great Lakes District held its annual meeting in Chicago, Ill., November 5, 1943, with 100 per cent representation of Sections. A. G. Dewars (M '27) District vice-president, presided.

M. S. Coover (F '42) professor and head of the department of electrical engineering, Iowa State College, Ames, was nominated for AIEE vice-president to represent the Great Lakes District, and J. A. Northcott, Jr. (M '40) head of the department of electrical engineering, University of Notre Dame, South Bend, Ind., was elected representative on the national nominating committee. N. C. Pearcy (M '30) acting treasurer, was elected District treasurer to succeed K. A. Auty (M '17) who resigned in January.

The meeting was addressed by L. A. Griffith, District vice-chairman of the national membership committee, who reported on the growth of membership in the District and presented curves showing the activities of each Section. The question of local memberships and the difficulty of getting local members to become national members was raised when a decrease in membership was reported for the Milwaukee Section. The Michigan Section stated that limiting local memberships to three years had solved that problem in its group.

It was suggested that each Section investigate the possibilities of subsections, following the lead of the Urbana and Madison Sections in establishing one each. Fargo–Grand Forks and Duluth–Superior were considered as possible subsection groups.

The question of collective bargaining and licensing laws for engineers was discussed at length.* As a result, the following resolution was proposed to be forwarded to AIEE headquarters: "Resolved, that the board of directors be requested to appoint a special committee to investigate encroachment of unionism into the province of engineering as a profession, and to formulate a policy to be followed with respect to collective bargaining, socialization of engineers, and related subjects."

In line with this resolution the executive committee requested that each Section within the District submit a report relative to labor-union encroachments in its area, and that it express an opinion on the resolution adopted.

Also discussed at length were the Kilgore–Patman bills (*EE, August '43, pp. 360–1; 381*) pending in the Senate and House of Representatives, which would pave the way for the socialization of engineers. It was recommended that, even though the Institute had already taken formal action in the matter, the Sections express themselves likewise by a vote of the membership. It was thought that a larger number of individual letters to Senators and Congressmen would exert more pressure than group action.

Professor M. M. Cory (F '40) chairman, District committee on student activities, stated that student memberships had decreased approximately 60 per cent because of enlistment and induction of students in the Armed Forces. In order to keep the Branches active, he recommended joint meetings with branches of the American Society of Civil Engineers, American Society of Mechanical Engineers, and other engineering organizations.

No District technical meeting will be held for 1944–45 because of wartime handicaps and since the 1944 AIEE summer technical meeting will be held relatively close to the Sections of the Great Lakes District.

*The board of direction of the American Society of Civil Engineers recently took action authorizing the formation of collective bargaining agencies for "professional engineering employees." See item in "Current Interest" section, this issue.

SECTION • • • • •

Use of Magnesium in Planes Topic of Milwaukee Section Meeting

Every American warplane built today utilizes more magnesium than its predecessor model, whereas German planes recently shot down show less magnesium than those shot down earlier in the war, explained Arthur Smith, Jr., of the Dow Chemical Company to over 200 engineers at a Milwaukee AIEE Section meeting recently.

Every cubic mile of sea water has 9,000,000,000 pounds of magnesium in it, and Americans are getting it into planes as fast as they can, with the result that some war planes have as much as half a ton of the metal. With these planes, American and British airmen have been bombing German magnesium plants as fast as they can, said Mr. Smith.

In 1938 production of magnesium was barely 2,000 tons, but the present production is over one hundred times that quantity. In some types of construction the use of magnesium alloys can save from 19 to 35 per cent in weight over aluminum, and so this new metal is used in aircraft and lightweight portable equipment wherever a change-over is possible without slowing production.

Portable tools, reciprocating high-speed machinery, trucks, busses, and airplanes will be the big postwar consumers of magnesium, Smith predicted.

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE winter technical meeting, New York, N. Y., January 24–28, 1944, and are expected to be ready for distribution within the current month. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the convention registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Air Transportation

44-29—Potential Breakdown of Small Gaps Under Simulated High-Altitude Conditions; *M. J. DeLorne (A '43). 15 cents.* Because of the variation in air pressure and temperature with altitude, the breakdown-

Future AIEE Meetings

Winter Technical Meeting
New York, N. Y., January 24-28, 1944

North Eastern District Meeting
Boston, Mass., April 1944

Summer Technical Meeting
St. Louis, Mo., June 26-30, 1944

Pacific Coast Technical Meeting
Los Angeles, Calif., Aug. 29-Sept. 1, 1944

potential characteristics of aircraft electric equipment differ from those of other pieces of industrial electric equipment. This paper shows the effect of altitude on the air-gap breakdown potential between hemispheres and between various current-carrying parts of typical aircraft equipment; the paper also shows the effect of altitude on creepage or surface breakdown for similar specimens. The effects of frequency and humidity on the breakdown characteristics are also investigated. Special considerations which may exist for aircraft electric equipment are taken into account when conclusions concerning the effects of the various factors mentioned are drawn.

44-32—Present D-C Aircraft Electric-Supply System; *H. C. Anderson, Jr.* (*A'43*), *S. B. Crary* (*M'37*), *N. R. Schultz* (*A'40*). *20 cents.* This paper presents the results of analytical investigations and laboratory and field tests on present 28-volt d-c aircraft electric systems. The paper deals with the performance of the various components of the electric-supply system as well as the operation of the system as a whole. The system problems investigated are: system-voltage accuracy, load division during parallel operation of generators, relay contactor chatter, generator-output capacity, effects of heavy transient loads, and short-circuit currents.

44-36—Basic Considerations in Selection of Electric Systems for Large Aircraft; *W. K. Boice* (*M'43*), *L. G. Lavoy, Jr.* (*M'43*). *30 cents.* This paper presents some of the considerations involved in selecting electric systems for large aircraft. Such systems now are undergoing intensive development, and, consequently, it is not possible to give complete answers to all problems which arise. Also, certain parts of the electric systems are subject to military classification and cannot be discussed. Nevertheless it is felt that many engineers, particularly those engaged in the design of such systems, will welcome a brief review of the basic factors involved. Industrial and central-station experience provide a valuable background for study of aircraft systems. However, too close an adherence to previous practice should not be maintained since aircraft systems differ in many ways from those of land equipment. The need for minimum weight demands that only those features be included which fundamental considerations show to be necessary or at least provide benefits which justify the weight involved. Hence, a review of the basic problems encountered should be helpful at this time.

44-38—Electric-Circuit Fault-Protective Principles as Applied to D-C Aircraft Systems; *R. H. Kaufmann. 30 cents.* Adequate fault protection assumes ever-increasing importance as the size and responsibility of aircraft electrical systems increase. Increased short-circuit current levels mean greater switching-equipment duty and potential fire hazard. Larger amounts of rotating load machinery introduce a problem of electrical stability and emphasize the need for rapid fault clearing. The purpose of this paper is to outline the characteristics of various applicable fault-detection devices and the manner in which they may be used most effectively in typical aircraft circuits. Important considerations to be recognized in judging the effectiveness of a particular system of fault protection include:

1. Reliability and selectivity—only fault protectors adjacent to an electrical fault can operate and do so reliably.

2. Operating speed—more rapid fault clearing diminishes fire hazard and improves operating stability of the remaining system.

3. Simplicity—simplicity of design, application, installation, and field maintenance are all important.

4. Cost in weight.

44-43—Testing Aircraft Generators; *H. E. Kenaipp* (*A'40*). *15 cents.* The modern fighting plane requires a large amount of electric power for its successful operation. The d-c aircraft generator provides a reliable source of power at the lowest possible weight. The development of these generators has required close co-ordination of design, testing, and interpretation of test results. The tests include raw material, laboratory, life, mechanical, and flight tests. Generator parts as well as complete machines are being tested continually. The generator test program has been responsible for the correction of troubles which have developed in the field and also for the elimination of potential sources of trouble. It has also been responsible for improvements in the use of material so that extremely low weight has been obtained. No untried parts or materials can be used in an aircraft generator. Laboratory tests must be relied upon for a preliminary check of all improvements before they are subjected to flight testing.

44-57—Effect of Altitude on Electric Breakdown and Flashover of Aircraft Insulation; *L. J. Berberich* (*M'36*), *G. L. Moses* (*A'43*), *A. M. Stiles* (*A'43*), *C. G. Veinott* (*M'34*). *30 cents.* The breakdown strength of air and the surface flashover behavior of a number of materials have been investigated under conditions corresponding to an altitude range from sea level to 65,000 feet. The various atmospheric conditions encountered by aircraft in this altitude range were simulated by use of a special test chamber. The pressures and temperatures were reproduced as well as the moisture, cloud, ice and snow conditions. Moisture in the condensed droplet form was found to lower both the breakdown strength of air and the flashover voltage of materials. On the other hand, moisture in the frozen form, such as ice, and snow, did not have any marked effect on either the breakdown strength of air or flashover behavior of materials. On the basis of extensive data given in the paper and general experience with various types of electric apparatus, specific striking and creepage or flashover distances have been proposed for aircraft electric equipment in the various voltage classes.

44-58—Electric-Circuit Burning-Clear and Damage Phenomena on Aircraft Structures; *C. M. Foust* (*M'31*), *J. G. Hutton. 20 cents.* Normal and continuous performance of electric circuits is a prerequisite to the effective use of airplanes. Electric short circuits, which result in the loss of power for vital control operations, or cause fires, are definite hazards. The extensive use of the 28.5-volt d-c aircraft systems, and the consideration being given a three-phase 208-volt 400-cycle a-c grounded neutral system for high-altitude planes necessitated an investigation into the burning-clear and damage phenomena on both circuits. Short circuits were applied on an aluminum alloy system of an airplane and oscillograms of short-circuit current and voltage taken. In both the a-c and d-c systems it was found that the fault-damage and burning-clear phenomena depended upon the energy level in the short-circuit area. When the contact area between the conductor and aircraft structure was small, the energy level was high and the fault burned itself clear. In such cases the aircraft structure was perforated. Increase in contact area and a consequent reduction in energy concentration resulted in a sustained fault current. In some of these cases a definite welding of the conductor to the aircraft structure occurred, whereas in others no burning took place.

44-59—Corona in Aircraft Electric Systems as a Function of Altitude; *W. R. Wilson. 20 cents.* Corona-starting voltages of the components of a 208-volt 400-cycle grounded-neutral electric system are reported for altitudes between sea level and 50,000 feet. The corona characteristics are shown to be functions of air pressure, electric-field geometry, humidity, and the cleanliness of insulating surfaces. The effect of reducing pressure is shown to lower the corona-starting voltages of aircraft cables by as much as 60 per cent, because the dielectric strength of large air gaps drops a comparable amount. Reducing the pressure has small effect on the corona-starting voltages of low-voltage capacitors, because the dielectric strength of small air gaps is nearly independent of pressure. Moisture and dust on insulating surfaces and moisture in aircraft cables produce coronalike disturbances below 208 volts. Data are presented on cables, capacitors, parallel studs, and needle gaps. Under dry conditions all corona-starting voltages were well above the operating voltage of the system.

Basic Sciences

44-24—Symmetrical-Components Analysis of the Four-Phase System; *A. Boyajian* (*F'26*). *15 cents.* Symmetrical-component concepts are developed for the currents, voltages, and impedances of a four-phase system, and formulas are given for various types of short circuits. The idea of symmetry among the members of each set is based on the angular displacement between the members of the set, rather than on phase rotation, which fits the three-phase case very nicely

but is inadequate for the four-phase case. Aside from its possible value for four-phase problems, which are rather rare, the paper is presented here in the expectation of an additional benefit, namely, that the parallelisms and contrasts between the four-phase and the three-phase formulas may throw further light on the general theory and applications of symmetrical components.

44-45—Some Aspects of Inductance When Iron Is Present; *L. T. Rader* (*A '34*), *E. C. Litscher. 30 cents.* There are three definitions of inductance commonly found in textbooks and handbooks. These all assume a straight-line saturation curve and so yield the same constant value. This paper attempts to show the errors inherent in such definitions when iron is present. Various definitions of inductance are examined in the light of the application where the term is used. Comparisons are made of four definitions for different flux densities. Consideration is primarily confined to circuits in which no air gap exists. Oscillograms are given showing the effect of saturation and eddy currents. An analytical expression for the saturation curve of silicon steel is presented by means of which the various definitions could be easily examined analytically. The use of the term inductance is examined in connection with welding of contactor tips, arc interruption of motor circuits, current build-up and decay of solid iron fields, and reactor circuits.

Communication

44-42—Crossbar Toll-Switching System; *L. G. Abraham* (*M '39*), *A. J. Busch* (*M '30*), *F. F. Shipley* (*application pending*). *25 cents.* A new mechanical toll-switching system developed by the Bell System was placed in service in August 1943 to handle calls originating or terminating in Philadelphia, Pa., or passing through it. Connections are established by crossbar switches under direction of common control equipment called senders and markers. For the greater part of the calls passing through the new toll office, no operating labor is required within the office itself. Some of the incoming trunks, however, are not arranged for dial operation, and calls coming in over these trunks are handled by operators at cordless positions equipped with key sets. Connections are made on a four-wire basis; that is, separate transmission paths are provided for the two directions of talking, and repeaters are switched in automatically when required. Compared with manual switching, the new system offers substantial improvements in quality and speed of toll service.

44-49—Automatic Ticketing of Telephone Calls; *O. A. Friend* (*M '31*). *25 cents.* There is being placed in commercial service by the Bell System in a suburb of Los Angeles a new arrangement of dial central-office switching equipment designed to enable subscribers to dial their own calls to other points in the metropolitan area without help of an operator, and thereby obtain the speed and convenience of direct dial service. The equipment automatically prepares a printed ticket showing the calling and called numbers and other information needed for charging for the call. The system is designed for application to areas employing central-office switching equipment of the step-by-step type and provides trunking features designed for efficient use of interoffice trunk plant in such metropolitan networks.

Electric Machinery

44-35—The Asymmetrical Stator as a Means of Starting Single-Phase Induction Motors; *J. L. Baum. 25 cents.* A single-phase induction motor with but one winding will have starting torque if the stator is not symmetric with respect to the center of each pole. This paper presents a mathematical analysis of this type of motor, deriving formulas to predict the performance and determine the effect of various details of design. Emphasis is placed upon the motor using a varying air gap. Sample calculations are included.

44-63—A Design Method for D-C Machines; *M. I. Burr* (*A '43*), *J. H. Karr* (*A '32*). *20 cents.* The design engineer is often confronted with the problem of making use of standard mechanical parts from which the required motor performance is obtained by properly proportioning of the armature and field windings. The method of machine design presented herein utilizes the full-load performance requirements from which the windings can be determined directly. The procedure does not present any new fundamental theory, but rather a difference in design approach, or viewpoint. The method is illustrated by the use of a numerical example showing a typical design of a d-c series motor and the test results of the particular design.

44-64—Starting Winding for Single-Phase Induction Motors; *C. G. Veinott* (*M '34*). *30 cents.* Methods are given to enable the design engineer to determine the best starting winding and the best capacitor, reactor, or resistor required to meet any specified requirements. The methods given have been in actual use by design engineers for over 12 years and are as useful today as they were when developed. Simple circle diagrams depict graphically the principles involved in the method. Some practical observations, based on experience, are given. A calculation form, with sample calculations, is also included.

44-65—Thermal Protection of Transformers Under Overload Conditions; *V. M. Montsinger* (*F '29*), *G. Camilli* (*F '43*). *20 cents.* Overloads in close agreement with the emergency overloads recommended both by the AIEE and American Standards Association (Test Code C-57.3) now can be obtained by the use of a relay controlled by a specially designed heating coil, the time constant of which is large in comparison with that of the winding. Similar results also can be obtained by the use of a heating coil, the time constant of which is about the same as that of the winding, for operating a relay that is compensated for changes in ambient temperature. A thermal protective system has been developed which will perform three separate functions: control fans, give a warning signal, and sound an alarm or if desired trip the transformer off the circuit. A diagrammatic sketch and photographic prints show the various combinations of bulbs and relays available. It is believed that the system allows transformers to be loaded more nearly in agreement with the recommended industry loadings than any previous available device.

44-66—Overloading of Transformers—Cases Not Covered by the General Rules; *W. C. Sealey* (*M '38*), *J. B. Hodtum* (*M '26*). *15 cents.* The general relations covering the heating of transformers and the effects of this heating on safe overloads are simple in principle, but the mathematics involved are complex. When suitable curves are used to express the relations, the simplicity is evident. Loading of transformers and other equipment by temperature is increasingly common and rightly so. An understanding of the principles involved aids in intelligent application of information for loading by temperature. The usefulness of the American Standard Guide for Operation of Transformers would be increased by the inclusion of temperature time charts so that a solution may be obtained for the unusual loading case. These charts are based on the same principles on which the present rules are based. In addition to simplifying the procedure for taking care of special cases, such charts present a graphic picture of the heating relations of transformers.

44-67—Effect of Altitude on Impulse and 60-Cycle Strength of Electrical Apparatus; *P. L. Bellaschi* (*F '40*), *P. Evans, Jr.* (*A '38*). *20 cents.* Altitude is accompanied by a lowering of the air density (*RAD*) and affects dielectric strength and thermal and other performance of electrical apparatus. Much research has been directed to these problems, but certain fundamental data are still lacking. The impulse and 60-cycle data in this paper should therefore be timely. The apparatus tested covers line and station insulators, bushings, wood crossarms and rod gaps; indoor apparatus; also insulation of engineering interest. The air strength of apparatus to $1^1/_5 \times 40$-microsecond waves can be considered proportional to *RAD*. Sixty-cycle strength and corona are similarly affected. *RAD* corrections for front-of-wave impulse are less. The oil strength of apparatus is practically unaffected. Humidity and other effects are influencing factors. Rating of apparatus for high altitude should recognize these facts.

Electronics

44-41—Rectifier Circuit Duty; *C. C. Herskind* (*M '40*). *20 cents.* The design and application of rectifiers may be considerably simplified and facilitated by defining the action in terms of:

1. The circuit duty imposed on the rectifiers by the current and voltage waves.

2. The rectifier capacity as measured in terms of the maximum circuit duty at which it is capable of operating successfully.

The circuit duty is determined by the constants of the a-c and d-c circuit, inasmuch as the function of the rectifying element is essentially that of a switch. With a knowledge of the circuit duty of the various rectifier

circuits, a given rectifying element may be used in new applications with full assurance if its capacity is known. This paper discusses eight specific factors which together define the circuit duty imposed on the rectifier. Various rectifier circuits are analyzed to show the functional relationship between these factors which define circuit duty and the circuit constants. The definition of circuit duty is essential to the engineer in the determination of the required rectifier capacity and the prediction of performance. The effect of phase control upon the circuit duty imposed on the rectifier is discussed. The factors relating circuit arrangement to the duty under fault conditions also are considered. A classification of the more common rectifier circuits on the basis of circuit duty is presented, and some of the factors entering into the choice of circuit for particular applications are discussed.

Industrial Power Applications

44-39—Supervisory Control for the World's Most Modern Steel Mill; *P. B. Garrett* (*M '30*), *M. E. Reagan* (*F '41*). *15 cents*. Although supervisory-control systems have been used previously to control the over-all main power supplies for steel mills, they have, for the first time, been applied to the entire electric-circuit control of a large installation. The chief advantages are to bring the control and supervision of all electric circuits to one central location where the dispatcher has, at all times, a complete, accurate survey of all the generating, and transmission and distribution circuits and to conserve vital war materials in the over-all construction program. The motor-room equipments are unattended, the starting and stopping operations being performed by the power dispatcher in a minimum of time. Power outages are quickly located and restored.

44-40—The Capacitor—An Aid to Electric-Power Service for Pipe Lines; *M. A. Hyde, Jr.* (*A '27*), *R. E. Marbury* (*M '36*). *25 cents*. In the over-all design of an electrified oil pipe line, power service constitutes a major problem, not only because of its importance in the economic structure, but also because it is a problem more varied in its component parts than almost any other phase of the project. Station designs are for the most part repetitive; power-service facilities up to the point of delivery vary widely from station to station. In the completion of three recent major pipe-line projects, power service has been facilitated in numerous instances by capacitors. In some cases, under conditions imposed by war time conservation of power-service materials, capacitors have been the key to successful station operation.

44-60—Heating of Nonmagnetic Electrical Conductors by Magnetic Induction—Longitudinal Flux; *R. M. Baker* (*M '40*). *30 cents*. Most induction-heating problems for the sake of calculation can be resolved into the problem of heating a cylinder, a flat slab, the surface of a slab by a current-carrying conductor near the surface, or some combination of these. This paper outlines the method and gives the necessary equations for calculating these three cases for nonmagnetic materials.

44-61—Electrical Equipment for the War Emergency Pipe-Line Projects; *E. E. Thomas* (*M '29*), *W. G. Taylor*, *Oscar Wolfe*. *25 cents*. The 24-inch and 20-inch electrically operated record-breaking oil and gasoline pipe lines extend across the country from Texas to the Atlantic Coast. This paper describes the projects, typical pumping-station equipment and methods of control, including an explanation of the automatic operating and protective features provided on the 20-inch pipe line. Discussions are given of the problems encountered in providing adequate single-phase protection, and in applying capacitors to improve unfavorable power conditions. Data are included to show engineering results obtained in applying power equipment under emergency war conditions.

Instruments and Measurements

44-21—A Multiplied-Deflection A-C Potentiometer; *R. B. Marshall* (*A '40*). *15 cents*. Several types of a-c potentiometers have been developed in past years, but each has been too complicated for common all-purpose usage. This paper describes a potentiometer that is unusually easy to operate and has many ranges. It is portable and suitable for field measurements at power frequencies. No effort was made to reduce the size and weight of the model described, but there is little doubt that it could be arranged as a very compact instrument with self-contained indicating instruments. Since the instrument is based on a null balance, it should be classified as a potentiometer. From another point of view it is an indicating-instrument range extender for the results are obtained by observing the deflections of indicating instruments. Volts or millivolts are observed on a 150-volt voltmeter and amperes or milliamperes are indicated on a five-ampere ammeter. Watts or milliwatt are indicated by a 500-watt wattmeter. Impedances as low as a small fraction of an ohm, and as high as thousands of megohms can be measured readily and their power factors determined.

44-35—Crossed-Coil Power-Factor Meters; *N. P. Millar* (*application pending*). *25 cents*. The increased demand for the measurement of power factor on single-phase and polyphase circuits has made it necessary to design instruments with a large number of scale ranges. Application of an instrument to a specified circuit condition and the scale range determine the scale distribution. The factors which control the scale distribution in the single-phase, three-wire two-phase, three-wire three-phase, and four-wire three-phase crossed-coil type of power-factor meter are shown from the respective fundamental relations. Although limitations on the scale range and distribution necessarily are imposed by mechanical design, a graph of either the equilibrium expressions or the torque of equations emphasizes the theoretical possibilities of scale ranges. These graphs aid materially in the selection of the proper scale range for a given scale angle of deflection.

44-31—Influence of Improved Magnetic Alloys on Design Trends of Electrical Instruments; *M. S. Wilson* (*M '43*), *J. M. Whittenton* (*A '37*). *15 cents*. This paper reviews briefly the magnetic alloys which have been utilized previously as magnets in d-c permanent-magnet moving-coil small-panel indicating instruments and describes the properties of a new cobalt–molybdenum–iron alloy which has definite advantages as a permanent magnet in electrical instruments because of its high magnetic strength and good machining qualities. The utilization of this new cobalt–molybdenum–iron alloy for the first time as a permanent magnet in an indicating instrument is described and illustrated. Comparison with a similar instrument having a magnet made of chrome steel demonstrates the improvement in over-all performance and reliability of a given rated instrument using this new magnetic alloy. Particular emphasis is given to the increased "mechanical factor of merit" which is a measure of instrument reliability and other improvements which result from the use of this material.

44-55—The Accuracy of Measurements in Lumped R-C Cable Circuits as Used in the Study of Transient Heat Flow; *Victor Paschkis*, *M. P. Heisler*. *20 cents*. Lumped resistance–capacitance circuits can be conveniently used for the investigation of transient-heat-flow problems. For this purpose a complete network, known as heat and mass-flow analyzer has been erected at Columbia University. This paper deals mainly with the various factors influencing the accuracy of the method. Specifically, the selection of the best number of lumps is analyzed. Two factors cause errors in the current and voltage readings: leakage in capacitors and insulation, and replacement of the "theoretical circuit" with evenly distributed properties (infinite number of lumps) by a circuit with finite number of lumps. From the viewpoint of leakage a small number of lumps is desirable; but from the viewpoint of replacing theoretical current by a lumped circuit a large number of lumps yields better results. Numerical values for the expected error resulting with various numbers of lumps are given. Final recommendations as to best practical lumping are made.

Land Transportation

44-20—Electrification of Large Open-Pit Copper Mines; *L. W. Birch* (*M '29*). *15 cents*. The transportation problem of a large strip mine involves the loading, hauling, and dumping of both ore and waste. These materials are loaded with large electric shovels operating on benches along the slope of a hill or pit. The ore is transported over main-line tracks to the reduction plant while the waste is hauled to suitable dumps. All main-line tracks are permanent and are equipped with permanent overhead distribution systems. All bench and dump tracks are portable and are equipped with portable overhead distribution systems. Sixty per cent of the world's copper is now obtained by open-pit mining of low-grade ore. Electrification of haulage ways for open-pit mining is keeping pace with the expansion and is modernizing the transportation of huge tonnages. Huge capacities necessitating heavy cars, and heavy grades demanding short-period overloads have been responsible for selecting the electric locomotive for motive power. From the standpoint of locomotive

capacity, rail size, dump-car capacity, and density of traffic, most open-pit electrifications compare in size with our large steam-road installations and hold an important place in the field of heavy traction. In addition to describing the haulage problem of large open-pit copper mines, this paper discusses the design of permanent and portable distribution systems.

44-25—Design Features of Generators for Diesel-Electric Switcher Locomotives; *C. A. Atwell* (*M '43*). *15 cents.* The present unparalled demand for movement of raw materials and finished products is demonstrating the convenience and effectiveness of the Diesel-electric switcher locomotive. This paper reviews both mechanical and electrical features of generators recently developed for use on the medium and smaller sizes of switcher locomotives. Mechanical features refer especially to mounting the generators and connecting them to the Diesel engine. Electrical performance both as power generators and as engine-starting motors are discussed, as well as the means for obtaining this performance simply and reliably.

44-26—Gear Ratio and Its Effect on Traction Motors; *G. M. Woods* (*M '43*). *15 cents.* The power of practically all traction motors is transmitted to the vehicle's axles by means of gears. Developments in gear design, gear materials, and heat treatments have permitted progressively greater gear reductions and, hence, the economical use of higher-speed motors. Higher speed results in less motor weight and space requirements. Present-day traction motors weigh only 1/4 as much as motors of similar capacity constructed 40 years ago. This reduction in size and weight has made possible the construction of vehicles which afford a superior service to the public and are economical in operation. In frequent-stop city service lower gear reduction on a specific motor results in slightly higher schedule speed with relatively great increase in energy consumption and motor-heating current.

44-27—Diesel-Electric Switching-Locomotive Application by Means of Nomographic Charts; *A. P. Millan, T. F. Perkinson. 15 cents.* The application of switching locomotives involves calculations of locomotive performance under given conditions of grade, train weight, and length of run. Such calculations can be made quickly by nomographic charts. Equipment-heating limitations on Diesel-electric and electric locomotives can also be checked by elements added to the nomograms. The theory and the method of construction of such charts are described in this paper.

44-28—Modern Electric Locomotives in Open-Pit Mine Haulage; *J. E. Borland, L. G. Riley. 15 cents.* For the economical haulage of large daily tonnages of ore and waste rock at the Morenci Mine of Phelps Dodge Corporation, electric locomotives were selected. There are now in use 16 125-ton 750-volt d-c trolley locomotives, especially designed for open-pit haulage service. These units are equipped with 500-ampere-hour 500-volt storage batteries for train movements on mining benches and other unelectrified temporary tracks. The locomotives also provide dynamic braking to assist in retarding loaded trains descending heavy grades. A number of 125-ton Diesel-electric locomotives are used also in limited waste haulage and miscellaneous duty.

Power Generation

44-30—Reclosing of Single Tie Lines Between Systems; *W. W. Parker* (*M '37*), *H. A. Travers* (*A '41*). *15 cents.* This paper presents practical information for guiding the application of high-speed reclosing of single tie-line interconnections following a fault. The system performance during a reclosing cycle is analyzed, and the factors affecting the choice of switching and control equipment are discussed. The relative merits of three-pole (gang-operated) and single-pole (individually operated) breakers are compared for a large number of typical cases in the form of curves plotted between the power transmitted to the receiver system and the electrical length of the line. These curves show that single-pole switching in many cases offers a marked advantage over three-pole switching from the standpoint of transient stability based on two wire to ground faults. Furthermore, additional advantages of single-pole switching occur because the majority of faults are single line to ground. The reduced voltage dips and decreased system oscillations with single-pole switching of such faults are also illustrated.

Power Systems Application of Carrier Current

44-34—A Versatile Power-Line Carrier System; *H. W. Lensner* (*A '43*), *J. B. Singel. 15 cents.* In recent years power-line carrier has been used for a number of functions in addition to relaying, such as telemetering, load control, and remote tripping. Any one function can be added to a carrier-relaying system merely by keying the transmitter. However, present-day installations often require that several quantities be transmitted over a single carrier channel simultaneously. In order to accomplish this, audio tones are added to the transmitter and tone filters to the receiver, each tone effectively providing an additional channel. A band-elimination filter is used to allow voice communication between stations without interfering with the tones. To perform these functions and meet different line-tuning problems, unit-type equipment for indoor or outdoor use which is readily adaptable to the requirements of specific installations has been developed. Each unit performs a basic function, and suitable combinations of units allow a variety of applications.

Power Transmission and Distribution

44-23—The Effect of Kilovar Supply on the Design of Systems for Load Growth; *T. W. Schroeder* (*A '37*), *J. W. Butler* (*M '38*), *N. H. Meyers* (*A '41*). *15 cents.* The benefits that can be obtained by the use of shunt capacitors in electric power systems have been discussed many times in technical literature. The shunt capacitor ability to improve voltage and load power factor, thereby reducing losses, releasing circuit capacity, and postponing the need for additional circuit capacity, has been employed many times where economic considerations have justified such use. Again, other discussions have shown that the greatest use of a given system investment may be had when the basic load kilovar requirements are supplied near the load by either capacitors or condensers. It is the purpose of the present paper to give some indication of the economics and the benefits to be gained from an over-all-system basis, by including the capacitor located, in general, near the load, in the system plans for load growth—thus combining the two major foregoing thoughts. A synthetic but somewhat typical system with steam and hydroelectric generation and industrial, commercial, and domestic loads was taken as the guinea pig. Operating conditions prevailing for present loads and future loads of approximately 165 per cent were studied. Alternative methods of taking care of the load growth and maintaining the same service requirements were compared from the operating and investment angles.

44-50—An Eight-Year Investigation of Lightning Currents and Preventive-Lightning Protection on a Transmission System; *E. Hansson* (*M '35*), *S. K. Waldorf* (*M '36*). *25 cents.* The paper presents a detailed analysis of surge-crest ammeter records collected on 308 miles of line. The distribution of strokes by years and by location has been reduced to numbers and found to be random. The protective value of different arrangements of counterpoise are compared, and the effects of bonding adjacent structures on line performance are shown. Evidence is presented which indicates that the surge impedance of conductors on transmission lines is less than 235 ohms. The data have been arranged with a view to using it for the predetermination of line performance from short-term records. Examples of such estimates are given and compared with actual experience. The frequency and magnitude of discharges through lightning arresters connected to well-protected lines are given.

44-52—Fusing Practices on Distribution Systems; *J. S. Parsons* (*A '27*), *J. M. Wallace* (*A '41*). *15 cents.* Data on the fusing of primary feeders and distribution transformers have been collected from more than 150 power companies. The paper presents an analysis and discussion of fusing practices based on these data and gives a summary of the data collected.

44-53—Current Rating of Cables as Affected by Mutual Heating in Air or Conduit; *Committee on Research, Insulated Power Cable Engineers Association. 30 cents.* Cables installed in a group in air, either in conduit or without conduit, can carry less current than a single isolated cable because of mutual heating from other cables in the group. This effect has been recognized, but no reliable data are available as to the magnitude of this effect. The Insulated Power Cable Engineers Association sponsored the series of tests reported in this paper to determine the correction factors which should be applied to the allowable loading of a single conduit to obtain the permissible loading for each conduit when installed in a group. Various

groupings of conduits were tested as well as groups having different numbers of conduits. From the data obtained a table of correction factors was determined. It is shown that these factors are independent of the type cable, kind of insulation, and the number of conductors per conduit, so that a single table may be used for all cables in conduits. Similarly, a second table gives the correction factors for groups of cables in air without conduit. This table is also independent of the type cable, kind of insulation, and the number of conductors in the cable.

44-34—Calculation of Unbalanced Voltage Drops in Distribution Circuits With Particular Reference to Multigrounded Neutrals; *W. R. Bullard* (*M '26*), *H. L. Lowe* (*M '38*), *H. W. Wahlquist* (*M '36*). *15 cents.* Basic vector relations underlying a simplified method of calculating unbalanced voltage drops in distribution circuits are presented. The method is applicable particularly to circuits in which phase-to-neutral mutual impedances differ materially from phase-to-phase mutual impedances, but in which individual impedances within each of the two groups do not differ greatly from each other. Most circuits having multigrounded neutrals are of this general type. The method provides for the combination of self- and mutual impedances in such a manner that calculation of voltage drops is reduced basically to a single vector multiplication of a current and an impedance for each phase conductor and for the earth-neutral combination treated as a single return conductor. In practice, the calculation of approximate voltage changes due to unbalanced loads is reduced to a simple algebraic process. Examples of practical working formulas and corresponding impedance data are given.

44-62—Costs Study of 69- to 345-Kv Overhead Power-Transmission Systems; *J. G. Holm* (*M '29*). *30 cents.* Capital and annual costs are determined for a number of power-transmission systems. The systems transmit up to 800,000 kw over distances up to 500 miles at voltages ranging between 69 and 345 kv. System costs are those which existed immediately preceding the current war and are based on data obtained from manufacturers of electric equipment as well as on actual data on a number of existing systems. Systems are equipped with devices for stability improvement. The results show that there is an economic relationship among the transmission voltage, the block of power transmitted, and the transmission distance. Expenditures for devices for increasing the system-stability limit have proved to be amply justified. A kilowatt-mileage region is outlined for which the transmission with 345 kv is more economical than with 230 kv. Curves are given from which costs of various power-transmission systems may be estimated. Costs are represented on a percentage basis in such a fashion that system costs may be easily evaluated at prices other than those taken in the study.

Protective Devices

44-37—High-Voltage Oil Circuit Breakers for Rapid Reclosing Duty; *A. W. Hill* (*M '41*), *W. M. Leeds* (*M '38*). *20 cents.* Experience has shown that high-speed reclosing of circuit breakers on transmission lines at voltages up to 132 kv can be of considerable value in maintaining system stability and continuity of service. This paper describes a new line of outdoor oil circuit breakers and the special design features making them suitable for 20- and 35-cycle reclosing duty at voltages as high as 230 kv. Data are included showing high-power laboratory short-circuit tests on these duty cycles at 138 kv and 230 kv at currents corresponding to three-phase duty of more than 2,500,000 kva.

44-44—The Geometry of Arc Interruption—II. Current Zero Phenomena; *E. W. Boehne* (*F '43*). *30 cents.* The manner in which the current is modified in the region of the current zero at which interruption takes place may enhance or jeopardize the circuit interruption. An abrupt interruption of current may produce lower or higher recovery rates, with either accompanied by higher transient recovery voltages. The advent of the modern air circuit breaker is recapitulating the early advances with oil. It has widened the practical possibilities of controlling the current-zero phenomena. Breakers are now available which, instead of producing an abrupt interruption near current zero, permit the current to be deflected in such a manner as to arrive at zero current at a time later than indicated by the normal path of the current. Since the rate of rise of recovery voltage is dependent upon the rate of decay of current, these factors are important to circuit-breaker performance. These phenomena are presented in a descriptive manner, which is backed up with a rigorous mathematical analysis which outlines in equation and curve form, the complete evolution of the recovery voltage characteristic as the current is modified from one extreme to the other. Oscillographic verification of the various recovery voltage phenomena are presented. The phenomena of damping take on a new aspect. The analysis, in effect, adds a new dimension to the rigorous treatment of circuit interruption and comes closer than previous simplifying assumptions to explaining the true nature of circuit performance during the period of current interruption. An attempt is made to exhibit this three-dimensional analysis graphically in such a way as to impart a broader insight into the handiwork of Mother Nature in one of her more legerdemainic moments.

44-46—The MHO-Carrier Relaying Scheme; *R. E. Cordray* (*M '43*), *A. R. van C. Warrington* (*A '31*). *25 cents.* Present-day distance and carrier relays are limited by the amount of power-swing current that they can allow to flow in a protected section of line without tripping. The longer the line, the less the power-swing current permissible, because distinction between swings and faults is not possible when the impedance seen by the relays for fault and normal conditions approaches the same magnitude. The method of plotting power-swing loci and relay characteristics on the same impedance diagram has facilitated the design of relays to trip not only on faults but on unstable load conditions, and to refrain from tripping on loads and power swings from which the system is considered likely to recover. The new relays measure admittance and are called mho units. A distance-carrier relay scheme has been based on these mho units which is very much simpler than the present distance-carrier relay circuits.

44-47—A Magnetic-Type Air Circuit Breaker for 15,000-Volt Services; *L. J. Linds* (*A '39*), *B. W. Wyman* (*A '40*). *15 cents.* This paper describes the development of a magnetic air circuit breaker of the Magne-Blast type for 15,000-volt services with an interrupting capacity of 250,000 kva. Magne-Blast circuit breakers previously developed for lower voltages demonstrated the effectiveness of rapidly increasing the electric resistance of the arc prior to interruption, both in reducing the short-circuit current and in reducing the rate of rise and magnitude of the recovery voltage. As the circuit voltage is increased, the arc resistance must be increased proportionally to obtain the same percentage reduction in current and rate of rise of recovery voltage. The higher arc resistance necessary for 15 kv is obtained by increasing the thermal efficiency of the interleaving arc chute. This arc chute is discussed in detail. Design features of the breaker are described, as well as its application to metal-clad switchgear. Complete test data and representative oscillograms are included to substantiate the interrupting rating assigned to this breaker.

44-48—A New Three-Element Current-Limiting Power Fuse; *H. L. Rawlins* (*M '41*), *H. H. Fahnoe* (*A '35*). *15 cents.* The reliable performance of the three-element current-limiting fuse in protecting potential transformers and small auxiliary power transformers has created a demand for higher-current ratings. Therefore, a new three-element current-limiting fuse with a continuous rating of 200 amperes has been developed for protection of motor starters at 2,500 and 5,000 volts and in ratings through 100 amperes at higher voltages to permit tapping small blocks of power from high-capacity systems. A description is given of the new three-element current-limiting fuse which utilizes a novel form of fusible element to combine high continuous current capacity in a small single-cartridge fuse with extremely fast melting on high values of short-circuit current. Data and oscillograms presented cover high-power laboratory tests which show that the full range of fault currents was interrupted without producing voltage surges in excess of 160 per cent of normal system peak voltage.

44-51—The Functions of Ground Preference in Carrier-Current Relay Schemes; *S. C. Leyland* (*M '43*), *S. L. Goldsborough* (*M '43*). *15 cents.* All of the more common present-day carrier-current relay systems employ a feature known as "ground preference" which insures that, during faults involving ground current, the ground relays supersede the phase relays in controlling the carrier and tripping functions. In general, the reasons for this arrangement are not well understood and it is the purpose of this paper to discuss the conditions where ground preference is required. The paper discusses specific system conditions which would cause trouble if the phase relays were not superseded by the ground relays. There are, also, certain conditions where the presence of ground preference causes undesirable results. These

conditions are discussed and solutions proposed. Certain other system conditions which require phase-relay preference rather than ground-relay preference are discussed.

44-56—A 500,000-Kva 7.5-Kv Air Circuit Breaker for Steel-Mill Service; *R. C. Dickinson (M '41). 15 cents.* Heretofore it has not been economically feasible to build a self-contained air circuit breaker for a rating of 500,000 kva at 7.5 kv. The developments leading to this rating are described. Also, a description of the breaker and the peculiar design problems are presented. Test data with oscillograms are shown.

44-68—System Voltages and Fault Currents Determined Easily on D-C Board; *C. E. Asbury (A '39). 20 cents.* A systematic method of procedure is outlined for obtaining symmetrical components of voltages and currents on the d-c calculating board. The positive-sequence network and a zero-sequence network with impedances reduced to one half are used. An analysis is given showing how all the necessary currents and voltages can be obtained simply from readings taken on these two networks.

Safety

44-22—Study of Artificial Respiration on Anesthetized Men; *W. B. Kouwenhoven (F '34), D. R. Hooker, J. A. York. 15 cents.* This paper describes the results of a study in which the Schaefer prone-pressure method, the modified prone-pressure method in which the hands are rolled or snapped off the subject's back, and the pole-top method were applied to anesthetized men. Three subjects were used in the investigation. The subject's normal breathing and his chest expansion and contraction were first measured in a conscious condition. While the subject was still conscious all three methods of artificial respiration were applied. Following this the anesthetic was given and when the subject was unconscious and completely relaxed the three artificial respiration tests were repeated. It was found that the air moved per respiration under artificial respiration is equal to or greater than the natural breathing of the conscious subjects and that all three methods of artificial respiration provide ample ventilation of the lungs, the pole-top method being slightly in the lead.

Domestic and Commercial Applications

44-69—The Vibration of Electrical Contacts; *M. N. Russell, Saul Keilien. 15 cents.* Objectionable effects of electrical contacts' vibrating during their "making" period are discussed. Contacts that do not "make" without vibration or without bouncing shorten the life of switching devices considerably, particularly in circuits involving high initial power surges. Means for suppression of contact vibration are discussed. The practical solution is given for knife-type contacts. Graphical explanation of preloaded contact springs is given. Tests of switching devices having properly designed contacts disclosed exceedingly long life, even when controlling circuits contained lamps as load.

PERSONAL ••••

Vannevar Bush (A '15, F '24) president, Carnegie Institution of Washington (D. C.), and Director of the Office of Scientific Research and Development has been awarded the Edison Medal for 1943 for "his contribution to the advancement of electrical engineering, particularly through the development of new applications of mathematics to engineering problems, and for his eminent service to the Nation in guiding the war research program." Doctor Bush, the 33d recipient of the Medal, was born in Everett, Mass., March 11, 1890, and was graduated from Tufts College with the degrees of bachelor and master of science in 1913; he has received honorary doctorates from that institution and from nine other leading colleges and universities. Previously he received the Levy Medal of the Franklin Institute (1928), the AIEE Lamme Medal (1935), the Holley Medal of the American Society of Mechanical Engineers, and the John Scott Medal of the Philadelphia City Trustees (1943). His first position was in the testing department of the General Electric Company, Schenectady, N. Y., in 1913. After a short time with the inspection department of the United States Navy, he was appointed to the faculty of Tufts College in 1914 as instructor in mathematics and in 1916 was made assistant professor of electrical engineering. In 1918 and 1919 he was engaged in research on submarine detection for the United States Navy. He was employed as consulting engineer by the American Radio and Research Corporation, Medford Hillside, Mass., from 1917 to 1922. Doctor Bush joined the staff of the Massachusetts Institute of Technology as associate professor of electric-power transmission in 1919, becoming full professor in 1923 and vice-president and dean of engineering in 1932. He was elected president of the Carnegie Institution of Washington in 1939. President Roosevelt appointed him chairman of the National Defense Research Committee in 1940, director of the Office of Scientific Research and Development in 1941, and chairman of the Joint Committee on New Weapons and Equipment of the Joint United States Chiefs of Staff in 1942. Particularly interested in the design of scientific calculating instruments, Doctor Bush is the builder of the differential analyzer and the author of "Operational Circuit Analysis" and joint author with W. H. Timbie of "Principles of Electrical Engineering." Doctor Bush is also a director of the Raytheon Manufacturing Company, a trustee of Tufts College, Brookings Institution, and the Woods Hole Oceanographic Institution; a regent of the Smithsonian Institution; a life member of the Massachusetts Institute of Technology Corporation; and a member of the business advisory council of the United States Department of Commerce (1939–41). His society affiliations include membership in the American Association for the Advancement of Science, the American Physics Society, the American Academy of Arts and Sciences, the American Philosophical Society, the American Society of Mechanical Engineers, and the Society for the Promotion of Engineering Education. He also is a member of Tau Beta Pi, sigma Xi, and Phi Beta Kappa.

Vannevar Bush

A. N. Goldsmith (M '15, F '20) consulting engineer, New York, N. Y., has been appointed vice-chairman of the Radio Technical Planning Board. Doctor Goldsmith received the degrees of bachelor of science from the College of the City of New York (1907), doctor of philosophy from Columbia University (1911), and the honorary degree of doctor of science from Lawrence College (1935). He was attached to the faculty of the College of the City of New York (N. Y.) from 1906 to 1923. He has been director of research for the Marconi Wireless Company of America (1917–19), and director of research, chief broadcast engineer, and vice-president of the Radio Corporation of America, New York, N. Y., (1919–33), and is the holder of more than 100 patents. Doctor Goldsmith is a charter member and fellow of the Institute of Radio Engineers, a member of that society's board of directors, and editor of the *Proceedings* of the IRE.

J. J. Booth (A '13, F '39) formerly assistant superintendent, maintenance department, Carnegie-Illinois Steel Corporation, Duquesne, Pa., has been appointed superintendent of that department. Mr. Booth has been associated with subsidiaries of the United States Steel Corporation since 1913 when he entered the electrical-engineering department of the Carnegie Steel Company's Edgar Thomson Works. He was transferred to the National Tube Company, Gary, Ind., in 1924 where he was assistant superintendent and later superintendent of the electrical department. Transferred to the Carnegie-Illinois Corporation in 1935, he became assistant superintendent of maintenance.

Tomlinson Fort (A '27, M '35) formerly assistant manager, central station sales department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed manager of the central-station department. Employed by the Westinghouse company since 1923, Mr. Fort was assigned to the sales department until 1927 when he was transferred to Albany, N. Y. From 1931 to 1940 he was attached to the company's New York, N. Y., office and in 1940 became assistant manager of the central-station department.

William Marcus Potts (A '36) chief electrician, Pacific Coast Borax Company, Boron, Calif., is not the William M. Potts who died in June 1943 as was erroneously reported in the November 1943 issue of *Electrical Engineering*. The latter was not an AIEE member.

F. E. Kulman (A '30, M '39) formerly junior engineer, electrical-engineering department, Consolidated Edison Company of New York (N. Y.), Inc., now a lieutenant in the United States Navy, is stationed at the Brooklyn (N. Y.) Navy Yard.

OBITUARY

Hamilton Gray Scott (A '11, M '15) former public-utility executive, died November 1, 1943, in New York, N. Y. Mr. Scott, who was born in Pate son, N. J., December 29, 1882, commenced his career as chief electrician for the Rogers Locomotive Works in Paterson, in 1905. In 1908 he was employed as a salesman for the Fletcher Stanley Company and from 1909 to 1912 by the Shelby (Ohio) Electric Company as salesman and southern sales manager. During 1912 he had charge of the power contracts for the Central Georgia Power Company, Atlanta. He held the positions of general manager and vice-president of the Virginia Power Company from 1912 to 1915 and that of vice-president from 1915 to 1918. Joining the Charleston Industrial Corporation in 1918 as president, he became chairman of the board in 1923. From 1923 to 1925 he was also president of the Columbia Gas and Electric Company and its subsidiaries. He organized the Fidelity Public Service Company, which eventually became the Public Service Company in 1927, and later organized the Memphis National Gas Company. He was chairman of the board of the Servel Corporation and helped form the Electrolux Servel Corporation. In addition he served as vice-president of the Union Gas and Electric Company and the United Fuel Company. He retired in 1926 but retained directorships in several corporations and in 1941 returned to active work to convert the Pathe Engineering and Tool Manufacturing Company, Long Island City, N. Y., to war production.

Howard Arthur Stanley (A '07, M '19) plant engineer, Berkshire Fine Spinning Associates, Providence, R. I., died October 18, 1943. Mr. Stanley, who was born July 6, 1884, in Beverly, Mass., received the degree of bachelor of science in electrical engineering from the University of Maine in 1905. He worked in the testing and construction department of the Stanley-G. I. Electric Manufacturing Company, Pittsfield, Mass., until 1907. He was employed as construction foreman for the General Electric Company in Schenectady, N. Y., from 1907 to 1909, and in Boston, Mass., from 1910 to 1912, and was transferred to the district engineer's office in 1912. Joining the Fall River (Mass.) Electric Light Company in 1914 as electrical engineer, he became general superintendent in 1916 and vice-president in 1928. In 1930 he was employed by the New England Power Engineering and Service Corporation, Boston. He commenced his association with the Berkshire Fine Spinning Associates in 1933 at Fall River and in 1937 was transferred to Providence, R. I. An active member of the AIEE Providence Section since its organization in 1920, Mr. Stanley served as Section chairman (1923–4) and at some time had been a member of each of the Section's committees.

Roy Edwin Reid (A '12) engineer, Portland, Oreg., died in October 1942. Born February 14, 1880, in Jacksonville, Ill., Mr. Reid attended the University of California. From 1900 to 1904 he was a tester in the electrical department of the Union Iron Works, San Francisco, Calif. In 1910 he worked as electrician for Natomas Consolidated of California and in 1911 for the Pacific Light and Power Corporation, Redondo Beach, Calif., and on the Los Angeles Aqueduct, Inyo-Kern, Calif. He was employed as electrician by the Powder River Gold Dredging Company, Sumpter, Oreg., from 1913 to 1922. Joining the South Park Dredging Company in 1922 he was employed as electrician at Fairplay, Colo., and from 1924 to 1928 as assistant superintendent at Featherville, Idaho, and Ashland, Oreg. He worked as an electrician for the Northwestern Electric Company, Portland, Oreg. from 1929 to 1933. In 1934 he was employed as engineer by the La Grange (Calif.) Gold Dredging Company and the Yuba Consolidated Gold Fields and became assistant superintendent for the latter company in 1935. In 1939 he was transferred to the operating department in Durham, Calif.

James Watt Cochrane (A '42) erecting engineer, Canadian General Electric Company, Ltd., Toronto, Ont., died November 6, 1943. He was born September 5, 1894, in Kincardine-on-Forth, Scotland, and started working as an apprentice in mechanical and electrical engineering for Robert Melvin and Sons, Alloa, Scotland, in 1908. In 1913 he went to sea for the J. R. Ellerman City Line operating in the East Indian trade as junior and senior engineer. From 1915 to 1918 he served in His Majesty's Royal Naval Reserve as engineer sublieutenant and was decorated with the Distinguished Service Order. From 1919 to 1921 he was employed as marine engineer by the Union Castle Mail Steamship Company and from 1921 to 1923 was occupied in erecting a turbogenerating station in Tanganyika Territory, East Africa, for the Metropolitan-Vickers Company, Ltd. Since 1924 he had been employed as construction engineer by the Canadian General Electric Company.

Frederick Hormah Reid (M '28) president of the Mountain States Telephone and Telegraph Company, Denver, Colo., died October 29, 1943. Mr. Reid was born in Inverness, Scotland, April 6, 1880. His first association with the telephone industry was as clerk to the superintendent of the Colorado Telephone Company, Denver, in 1902. In 1904 he was made chief clerk to the general superintendent and in 1907 chief clerk to the general manager. He joined the Mountain States company as assistant to the general manager in 1914, and in 1915 became assistant general manager. He was appointed general manager in 1920. After serving as vice-president of the Southern Bell Telephone and Telegraph Company, Atlanta, Ga., from 1922 to 1924, he returned to the Mountain States company as president. Mr. Reid was a former president of the Telephone Pioneers of America.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on December 22, 1943, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Brandon, M. M., associate elec. engrs., Underwriters Labs., Inc., New York, N. Y.
Schilling, E. W., head, dept. of elec. engg., and Dean of engg., Montana State College, Bozeman, Mont.
Shuler, Wm., mgr., elec. engg., Records, inspection, and testing div., Dayton Power & Light Co., Dayton, Ohio.

3 to grade of Fellow

To Grade of Member

Albrecht, H. C., asst. chief engr., Philadelphia Electric Co., Philadelphia, Pa.
Arndt, M. H., head, Steam Plants Unit, Rural Electrification Adm., St. Louis, Mo.
Beechley, F. W., district engr., Westinghouse Elec. & Mfg. Co., San Francisco, Calif.
Bennett, W. R., member of technical staff, Bell Telephone Labs., Inc., New York, N. Y.
Blackburn, J. L., relay application engr., Westinghouse Elec. & Mfg. Co., Newark, N. J.
Boldt, W. F., elec. engr., Curtiss-Wright Corp., Robertson, Mo.
Brockhuysen, W. C., elec. engr., American Machine & Foundry Co., Brooklyn, N. Y.
Brown, W. A. R., Section chief, RCA Frequency Bureau, New York, N. Y.
Caswell, W. L., prof. of elec. engg., Iowa State College, Ames, Iowa.
Cavagnaro, A. E., engr., Columbia Engg. Corp., Cincinnati, Ohio.
Cline, R. F., research elec. engr., Norton Co., Chippawa, Ont., Can.
Cole, J. D., elec. engr., Russell Electric Co., Chicago, Ill.
Daily, C. F., engr., American Tel. & Tel. Co., Cincinnati, Ohio.
Davis, R. F., engr., American Tel. & Tel. Co., New York, N. Y.
Harmer, W. R., supervising industrial engr., Hydroelectric Power Comm. of Ontario, Toronto, Can.
Herring, F. M., senior engr., Baltimore Transit Co., Baltimore, Md.
Horn, R. C., engr., Southwestern Bell Telephone Co., St. Louis, Mo.
Lane, K. A., investigator of plant tests, Conowingo Hydro Plant, Conowingo, Md.
Lutz, R. F., consulting engr., Black & Veatch, Kansas City, Mo.
Mascott, Luis, engr. and professor, Mexico, D. F., Mexico.
May, M. S., service mgr., Speer Carbon Co., St. Mary's, Pa.
McCann, G. D., transmission engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
McMains, T. F., division traffic supt., Western Union Telegraph Co., New York, N. Y.
Menut, J. G., principal engr., (P-6) Power Section, War Department, Washington, D. C.
Miller, E. F., elec. engr., Iowa Illinois Gas & Elec. Co., Rock Island, Ill.
Phillips, A. H., chief elec. engr., Gilbert Associates, Inc., Reading, Pa.
Pierson, W. H., elec. designer, Chemical Construction Corp., New York, N. Y.
Richardson, A. G., senior engr., Federal Telephone & Radio Labs., New York, N. Y.
Schroeder, T. W., elec. engr., General Electric Co., Schenectady, N. Y.
Shelby, R. E., development engr., National Broadcasting Co., New York, N. Y.
Shipley, R. B., asst. elec. engr., U. S. Navy Yard, Philadelphia, Pa.
Smith, F. W., associate professor of elec. engg., Lafayette College, Easton, Pa.
Streifus, C. A., elec. engr., Ebasco Services, Inc., New York, N. Y.
Sunde, E. D., member of technical staff, Bell Telephone Labs., Inc., New York, N. Y.
Uhlendorf, E. D., vice-president, Public Utility Engg. & Service Corp., Chicago, Ill.
Zuch, H. W., chief elec. engr., University of Texas, Austin, Texas.

36 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. Any member objecting to the election of any of these candidates should so inform the national secretary before December 31, 1943, or February 31, 1944, if the applicant resides outside of the United States or Canada.

To Grade of Member

Adams, J. T. (Reelection), Pub. Service Co. of Okla., McAlester, Okla.

Baier, J. F., E-J Electric Installation Co., Louisville, Ky.
Bottini, S. D., A. Neri, Inc., Hoboken, N. J.
Curtiss, W. R., Great American Industries, Meriden, Conn.
Donald, D. D., American Tel. & Tel. Co., New York, N. Y.
Douglass, D. D., Chevrolet Gear & Axle Div. of G. M., Detroit, Mich.
Drago, F. G. S., British Admiralty Tech. Mission, Ottawa, Ont., Can.
Drummond, W. D. (Reelection), Westinghouse E. & M. Co., Cincinnati, Ohio.
Dunlop, C. E., Perron Gold Mine, Ltd., Perron, Que., Can.
Easton, E. C. (Reelection), Harvard Univ., Cambridge, Mass.
Etheridge, H. L. (Reelection), Senior Electrical Engineer, U. S. Army, New York, N. Y.
Eyford, C. T., British Columbia Elec. Ry. Co., Ltd., Vancouver, B. C., Can.
Feldman, J. G. (Reelection), Rolins Co., New York, N. Y.
Flaherty, E. B., Lieut. Comdr., USNR, New York, N. Y.
Frost, D. K., Mattison Machine Works, Rockford, Ill.
Gates, H. L., Petroleum Adm. for War, Washington, D. C.
Hayzarth, R. H., Dravo Corp., Pittsburgh, Pa.
Keller, R. A., Central Ill. Light Co., Peoria, Ill.
Kennedy, J. H., Tenn. Valley Authority, Knoxville, Tenn.
Kent, W. (Reelection), General Electric Co., Fort Wayne, Ind.
Kewley, R. K., J. I. Case Co., Rockford, Ill.
Kumbo, E., Brewster Aeronautical Corp., Long Island City, N. Y.
Locke, M. W., Commonwealth Edison Co., Pekin, Ill.
Lukey, M. E., Public Service Co. of Northern Ill., Chicago, Ill.
Moore, M. M. (Reelection), Federal Power Commission, Washington, D. C.
Nicholas, T. E., Simmons Aerocessories, Long Island City, N. Y.
Poulter, R. C., Hugh McLean Publications, Ltd., Toronto, Ont., Can.
Price, J. B. (Reelection), Johnson Fan & Blower Corp., Chicago, Ill.
Ross, F. U., Virginia Elec. & Pr. Co., Portsmouth, Va.
St. John, M. C., U. S. Engineer Office, Galveston, Texas.
Saveland, B. W., The Austin Co., Cleveland, Ohio.
Schoel, W. A. (Reelection), Boeing Aircraft Co., Seattle, Wash.
Schon, E. E., Allis-Chalmers Mfg. Co., West Allis, Wis.
Smith, F., Supt. of Fire Alarm, City of Tulsa, Okla.
Smythe, K. R., Glenn L. Martin Co., Baltimore, Md.
Sullivan, W. G., Research Corp., Bound Brook, N. J.
Thompson, H. H., Indiana Bell Tel. Co., Indianapolis, Ind.
Walkup, J. F., Parkhill-Wade, Los Angeles, Calif.
Wallace, W. H., Brooklyn Edison Co., Brooklyn, N. Y.
Ward, D. J., Ward Research Products Co., Sherman Oaks, Calif.
Wendt, W., Gulf States Utilities Co., Beaumont, Texas.
Wieking, W. C., R. Hoe & Co., Inc., New York, N. Y.

42 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Bernard, J. A., Bethlehem-Hingham Shipyard, Inc., Hingham, Mass.
Eichelberger, W. F., Central N. Y. Power Corp., Syracuse, N. Y.
Guile, M. E. Jr., Gen. Elec. Co., Schenectady, N. Y.
Miller, L. M., Eastman Kodak Co., Rochester, N. Y.

2. Middle Eastern

Barger, C. A., American Shipbuilding Co., Lorain, Ohio.
Baylis, A. H., Westinghouse E. & M., East Pittsburgh, Pa.
Blair, F. O., B. F. Goodrich Co., Akron, Ohio.
Chandler, A. H., Consolidated Gas Elec. Lt. & Pr. Co. Baltimore, Md.
Eickhoff, O., Jr., I-T-E Circuit Breaker Co., Philadelphia, Pa.
Kopp, F. C., Bethlehem Steel Co., Sparrows Point, Md.
Kovach, L. D., American Shipbuilding Co., Cleveland, Ohio.
Lang, M. T., West. E. & M. Co., Baltimore, Md.
MacKenzie, K. W., West. E. & M. Co., Cleveland, Ohio.
Mann, C. A., West. E. & M. Co., Cleveland, Ohio.
McAdie, C. H., Monitor Controller Co., Baltimore, Md.
Mumma, R. E., National Cash Register Co., Dayton, Ohio.
Niedeck, A., Lehigh Valley R.R., Bethlehem, Pa.
Outram, R. A., American Aircraft Associates, Dayton, Ohio.
Partridge, P. N., U. S. Navy Dept., Washington, D. C.
Radcliffe, G. B., Trumbull Elec. Mfg. Co., Norwood, Ohio.
Sacksteder, A. J., Frigidaire Plant #2, Moraine, Ohio.
Scheide, C. W., American Shipbuilding Co., Lorain, Ohio.
Shockney, J. M., Greenville Elec. Light & Power Co. & Affiliated Companies, Greenville, Ohio.
Smith, E. R., Ohio Pub. Service Co., Warren, Ohio.
Smith, H. C., Bell Tel. Labs., Inc., Cleveland, Ohio.
Stowe, R. E., Westinghouse E. & M. Co., Dayton, Ohio.
Tibbs, R. H. (Reelection), Chesapeake & Potomac Tel. Co., Washington, D. C.
Turnbull, E. H., Jr., Naval Research Lab., Washington, D. C.

3. New York City

Abolin, A., S. S. White Dental Mfg. Co., Staten Island, N. Y.
Anderson, F. C. (Reelection), T. A. Edison, Inc., West Orange, N. J.
Batt, L. T. (Reelection), Pub. Serv. Elec. & Gas Co., Newark, N. J.
Brauner, O. A., Gielow, Inc., New York, N. Y.
Camp Sergei, N., Lieut., U. S. Army, Middle Village, N. Y.
Causin, R., Standard Switchboard Co., Brooklyn, N. Y.
Ciprianani, C. J., 46 Davis Road, Port Washington, N. Y.
Cline, D. E., Signal Corps Laboratories, Eatontown, N. J.
Colman, A., Electro Tech. Labs., Inc., Leonia, N. J.
Davis, H., Wright Aeronautical Corp., Woodridge, N. J.
Duell, P. G., F. L. Smidth & Co., New York, N. Y.
Dusenberry, C. K., Wright Aeronautical Corp., Woodridge, N. J.
Eckert, J. R., Wright Aeronautical Corp., Woodridge, N. J.
Farrell, R. P., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Forsberg, A. W., Gen. Aviation Equip. Co., New York, N. Y.
Goldman, S., Bugue Elec. Co., Paterson, N. J.
Hagen, T. O. S., Board of Transportation, City of New York, N. Y.
Hammell, S. C., Wright Aeronautical Corp., Woodridge, N. J.
Hill, L. P., Federal Tel. & Radio Corp., East Newark, N. J.
Jones, M. A., N. J. Bell Tel. Co., Newark, N. J.
Kaitbah, E. E., Cont. Edison Co. of N. Y., Inc., New York, N. Y.
King, E., Todd Shipyards Corp., Hoboken, N. J.
Kraus, T., Gielow, Inc., New York, N. Y.
Kronmenhoek, C., Todd Shipyards Corp., Hoboken, N. J.
Larkin, J., Century Elec. Co., New York, N. Y.
Lucas, W., General Cable Corp., Perth Amboy, N. J.
Marino, D. A., George G. Sharp, New York, N. Y.
Matthews, M. T., Standard Oil Co. of N. J., Elizabeth, N. J.
Metz, R. P., Westinghouse E. & M. Co., Newark, N. J.
Morrison, J. W., Pub. Service Elec. Lab., Maplewood, N. J.
Neri, J. M. (Reelection), A. Neri, Inc., Hoboken, N. J.
Nordlindh, H., Gibbs & Hill, Inc., New York, N. Y.
Offrell, T., F. L. Smidth & Co., New York, N. Y.
Osceroff, D. M. (Reelection), J. G. White Engg. Corp., New York, N. Y.
Schultheis, T. W., Bell Tel. Labs., Inc., New York, N. Y.
Somers, F. C., Standard Oil Dev. Co., Elizabeth, N. J.
Swedlow, S., C. J. Tagliabue Co., Brooklyn, N. Y.
Taylerson, J. E., Federal Shipbldg. & Dry Dock Co., Port Newark, N. J.
Vine, E. L. (Reelection), James Stewart & Co., New York, N. Y.
Volavka, W., Long Island Ltg. Co., Mineola, N. Y.
Wendelken, G. J., Sperry Gyroscope Co., Brooklyn, N. Y.
Werts, R. J., Cameron Mach. Co., Brooklyn, N. Y.
Yates, F. A., Diehl Mfg. Co., Somerville, N. J.
Young, T. J. (Reelection), Bell Tel. Labs., Inc., New York, N. Y.
Zeese, A. C., Cons. Edison Co. of N. Y., Inc., New York, N. Y.
Zugale, F. J., N. J. Bell Tel. Co., Newark, N. J.

4. Southern

Adams, R. B., Tenn. Valley Authority, Knoxville, Tenn.
Alleman, J. J., Mathieson Alkali Works, Lake Charles, La.
Barnette, N. H., Louisiana Poly. Tech. Inst., Ruston, La.
Bell, P. M., Holston Ordnance Works, Kingsport, Tenn.
Brown, D. M., Tenn. Valley Authority, Chattanooga, Tenn.
Freeland, W. T., Freeland & Olschner Prod., Inc., New Orleans, La.
Griffith, J. C., General Electric Supply Corp., Shreveport, La.
Hoffman, G. H., Allis-Chalmers Mfg. Co., Knoxville, Tenn.
Kirby, L. W., U. S. Engr. Office, Norfolk, Va.
Moore, L. F., Knoxville Elec. Pr. & Water Board, Knoxville, Tenn.

5. Great Lakes

Bridgeman, M. J., A. O. Smith Corp., Milwaukee, Wis.
Canepa, T. T., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Crouch, A. W., Allison Div., General Motors Corp., Indianapolis, Ind.
Dernbach, C. R., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Dowling, J. J., Gen. Elec. X-Ray Corp., Chicago, Ill.
Hook, M., Howell Electric Motors Co., Howell, Mich.
Larsen, O. F., Harnischfeger Corp., Milwaukee, Wis.
Lowman, C. S., Commonwealth Edison Co., Chicago, Ill.
Martin, C. R., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
McAleer, G. H., Commonwealth Edison Co., Chicago, Ill.
Moyer, C. O., South Bend Elec. Co., Inc., South Bend, Ind.
Pellabek, R. A., Allis-Chalmers Mfg. Co., West Allis, Wis.
Powers, R. I., Wisconsin Electric Power Co., Milwaukee, Wis.
Ray, L. L., General Electric Co., Fort Wayne, Ind.
Rockafellow, S. C., A-C Spark Plug Div., General Motors Corp., Flint, Mich.
Wallace, R. S. (Reelection), Central Illinois Light Co., Peoria, Ill.
Saxe, M. J., Oliver Farm Equip. Co., South Bend, Ind.
Schindler, C., Kyle Corp., South Milwaukee, Wis.
Seymour, G. E., Hercules Powder Co., Baraboo, Wis.
Stukey, D. C. (Reelection), Public Serv. Co. of Northern Ill., Evanston, Ill.
VanRyan, A. (Reelection), Kyle Corp., So. Milwaukee, Wis.
Velde, R. L., Illinois Inst. of Tech., Chicago, Ill.
Wurgler, J., Allis-Chalmers Mfg. Co., Milwaukee, Wis.

7. South West

Anthony, W. F., S. W. Bell Tel. Co., St. Louis, Mo.
Benson, C. V., Pub. Service Co. of Okla., Tulsa, Okla.
Campbell, M. P., North American Aviation, Kansas City, Kans.
Ely, W. F., Univ. of New Mexico, Albuquerque, N. Mex.
Learn, H. P., Rural Elec. Adm., St. Louis, Mo.
Lyttle, W. F., Beech Aircraft Corp., Wichita, Kans.
May, H. L., S. W. Bell Tel. Co., St. Louis, Mo.
Mills, J. O., Pub. Service Co. Okla., Tulsa, Okla.
Stuart, J. F., El Paso Electric Co., El Paso, Texas.
Wiley, J. B., Univ. of Oklahoma, Norman, Okla.
Woodson, R. K. (Reelection), Kansas City Pr. & Lt. Co., Kansas City, Mo.

8. Pacific

Bystrom, A. F., Western Union Tel. Co., Los Angeles, Calif.
Eggers, F. A., Gen. Elec. Co., Los Angeles, Calif.
Gunderson, M. F., Douglas Aircraft Co., El Segundo, Calif.
Miller, D. L., Douglas Aircraft Co., Santa Monica, Calif.
Rife, J. E., Bureau of Power & Light, City of Los Angeles, Calif.
Smithen, W. E., Jr., General Engg. & Dry Dock Co., Alameda, Calif.

9. North West

Beadle, T. W., Lieut., U. S. Army, Seattle, Wash.
Bolluyt, M. A., Lieut., U. S. Army, Seattle, Wash.
Culnan, G. L., Austin Co., Seattle, Wash.
Gregg, T. S., Bonneville Power Admn., Portland, Oreg.
Hanson, L. P., Boeing Aircraft Co., Seattle, Wash.
Scoville, C. J. (Reelection), Portland Gen. Elec. Co., Portland, Oreg.
Templeton, L. F., Boeing Aircraft Co., Seattle, Wash.

10. Canada

Barr, W. G. A., Norton Co., Niagara Falls, Ont., Can.
Lees, D., Canadian Westinghouse Co., Ltd., Toronto, Ont., Can.
Robertson, T. C., Int'l Nickel Co., Ltd., Copper Cliff, Ont., Can.

Elsewhere

Adams, A. J. (Reelection), U. S. Govt., Seward, Alaska.
Aguirre Torres, J., General Electric, S. A., Mexico, D. F., Mex.
Campos Efrain, N., Int'l Automatic Elec. Corp., Mexico, D. F., Mex.
Ceballos, E. D., Cia. de Luz y Fuerza de Tehuacan, Tehuacan, Pue., Mex.
Cerda, J. M., Consulting Engineer, Mexico, D. F., Mex.
Cordero Gutierrez, E., Westinghouse Elec. Int'l Co., Mexico, D. F., Mex.
Dogra, H. C., S. D. O. E. & M. (A), Khamaria, Jubbulpore, C. P., India.
Doughman, G. B., General Electric, S. A., Monterrey, N. L., Mex.
Frias, Guzman, L., Centro Electrico, SRL, Puebla, Pue. Mex.
Garate Valdes, V., Santa Maria de la Paz y Anexas,, S. A., Matehuala, S. L. P., Mex.
Garcia Acosta, J., Industrial Electrica de Socoxuco, S. A., Tapachula, Chis., Mex.
Gonzalez Campos, E., Electrical Engineer, Torreon, Coah., Mex.
Guzman, C. V., National Economy Secrty, Mexico, D. F., Mex.
Hanft Castellanos, L., New Tequisquiac Tunnel, Mexico, D. F., Mex.
Horrocks, P., British Post Office Engg. Dept., Bolton, England.
Morales Garza, G., Railway Div., Mexican Government, Mexico, D. F., Mex.
Nieto, P. E., Comision Federal de Electricidad, Mexico, D. F., Mex.
Padilla de la Pena, A., Construccion y Maquinaria, Mexico, D. F., Mex.
Padilla Soto, F., Fabrica de Ceremica Ind., "El Aguila," Mexico, D. F., Mex.
Portugal Perez, J., Maquinaria y Materiales Electricos, Mexico City, D. F., Mex.
Rangel L., R., Sociedad Electro-Mecanica S. de R. L., Mexico, D. F., Mex.
Rosales de la Mora, A., Fabrica Nacional de Polvora, Sante Fe, D. F., Mex.
Souza Quevedo, V. (Reelection), Electrical Contractor, Mexico, D. F., Mex.
Taylor, W. H., General Electrics, S. A., Mexico, D. F., Mex.
Torres Aranda, F. (Reelection), Communications & Pub. Utilities Dept., Mexico, D. F., Mex.
Ulloa Arriola, C., Municipal Water Service, Mexico, D. F., Mex.
Villareal, E. M., Brown Boveri & Co., Mexico, D. F., Mex.
Zironi, E. W., EJE-Ingenieros, F. N. I., Mexico, D. F., Mex.

Total to grade of Associate
United States and Canada, 134
Elsewhere, 28

OF CURRENT INTEREST

ASCE Adopts Procedure for Collective Bargaining

Of significance to engineering employees in all fields of the profession was the action taken by the board of direction of the American Society of Civil Engineers at its recent meeting in Atlanta, Ga., when it approved and adopted a procedure for establishing collective-bargaining agencies for "professional engineering employees."

Upon the basis that the principle of collective bargaining has gained widespread acceptance in the past decade, and that its continued application is as inevitable as it is restrictive of the prerogatives of professional status, the board acted to assure ASCE members bargaining representation in groups of their own choosing. In past instances when professional engineers have failed to act together, nonprofessionals have assumed the right to bargain for them and have been given that right by the War Labor Board. Formation of a group which will be recognized legally as the collective bargaining agent exclusively for professional engineers was the only alternative to bowing before the authority vested in other unions of a subprofessional or nonprofessional level.

Long under consideration, the board's action was precipitated by the recent refusal of a War Labor Board panel at Kansas City, Mo., to recognize a group of about 100 engineers as a separate bargaining unit at the Sunflower Ordnance Plant. The reason given for the refusal was that the International Federation of Technical Engineers, Architects, and Draftsmen's Unions had been recognized for almost a year as spokesmen for technical men on the job. Inference from the panel's findings being that the engineering group would have been entitled to separate recognition had it acted when the matter of representation first was under consideration, the ASCE has prepared the foundation for organization against the time when concerted action shall be needed.

As recommended by the board of direction, the local sections of the ASCE will amend their constitutions so as to provide for engineering employees within their respective areas to form such employee bargaining groups. The Society will act as a national co-ordinating agency, and to this end will subscribe $50,000 annually for the maintenance of four field representatives, to be operative in each of the Society's zones, who will organize, advise, and assist the local groups. Moreover, in many cases, they may find it practicable to conciliate differences without the aid of the proposed bargaining groups.

At the start the local collective bargaining agency will be a subsidiary of the local ASCE section, but provision is made for nonmembers of the ASCE who are otherwise eligible to become affiliated. It is proposed to exclude from membership in the bargaining groups subprofessional men engaged in engineering work, and also, qualified professional engineers whose present positions place them in the employer rather than the employee category. To this end, the board of direction has formulated the following definition:

> The designation "professional engineering employees" . . . shall be that of only those who . . . possessing an intimate knowledge of mathematics and the physical sciences gained by technological and scientific education, training, and experience, and in a position of trust and responsibility, apply their knowledge in controlling and converting forces and materials to use in structures, machines, and products, and whose work requires the exercise of discretion and judgment, is creative and original and of such character that the output cannot be standardized; and those who, without the experience set forth, but having been graduated from an approved educational institution and having received the degree of bachelor of science or its equivalent, in engineering, are engaged in engineering work.

Dues have been tentatively set at $1 per year for members of the ASCE and "preferably not to exceed $5 per year" for non-ASCE members. The bargaining committee will have the duty and power to direct all activities looking toward the acquisition of adequate compensation and satisfactory working conditions for all professional engineering employees resident within the geographical limits of the local section in accordance with the general direction of its members.

WPB Opens Campaign to Augment Dwindling Paper Supply

With the waning of the first enthusiasm for salvage pervading the public in the days immediately following Pearl Harbor; the decline in man power available for curing wood pulp; and the sharp increase in military demand for paper by our widespread forces, the problem of paper supply has entered its crucial stage. According to War Production Board estimates, the success or failure, during the first six months of 1944 of its program of conservation by curtailment of the necessary uses of paper, and of salvage and re-use of waste paper should answer any questions about the severity of future curtailments.

An indication of the manner in which military demands have eaten into a civilian paper supply already below normal because of man-power shortages for timber cutting is found in the fact that for only the first year of the present war ten times the supplies and equipment used in 1917–18 were shipped abroad. Paper for shell containers, protectors, medical kits, food containers, clerical purposes, inner-packaging material, instrument panels, targets, component parts of bombs and fuses, gas-mask canisters, helmets, and building paper and board for cantonments can be secured by reprocessing waste paper. If the waste paper is not forthcoming, military demands will hold priority on wood pulp ordinarily used for printing. Compared with 43 tons of supplies per month per man in the last war, 81 tons of supplies must be packed monthly using one or more paper products, to keep each fighting man overseas in World War II. Since re-using waste paper performs the multiple duties of increasing the paper supply; of helping solve the scarcity of man power in the wood-pulp industry by directly replacing pulpwood; and of affording opportunity for larger numbers of people to assist in the paper program, the Government is giving wide publicity to the facts about the waste-paper salvage program in an effort to gain the co-operation of all. This latest program, unlike the successful February-March 1942 salvage campaign, is laboring under the added difficulty of diminished amounts of potential waste as a result of curtailment regulations already in force and the impossibility of recovering paper going to the fighting forces abroad.

One obstacle to the continuance of the last campaign has been eliminated. At that time, when the supply of waste paper was plentiful the mills engaged in converting waste paper were forced to curtail operations because of contract cancellations and manufacturing restrictions, and the resulting excessive supply broke the ceiling price for the paper. Under present agreements, eastern and western members of the waste-paper-consuming industries will purchase, at ceiling price, all paper collected and properly processed by February 15. These industries are faced with the necessity for an increase of 1,000,000 tons a year in waste-paper collections to offset a 50-per-cent drop in their inventories in the period of 12 months preceding September 1943.

Although the effect must be necessarily less immediate than that of waste salvage, since the war is largely responsible for the fall in production, the government is endeavoring to stimulate production of pulpwood. The Canadian paper industry which supplied nearly three fourths of our newsprint also is suffering from lack of man power to cut timber. In addition to this handicap, Canada also has diverted electric power normally used in pulp and paper mills to other war factories, and in 1944 a still greater curtailment in Canadian production is anticipated. Pulpwood imports from Norway and Sweden cannot be resumed until the successful termination of the war in Europe. With no chance of increasing imports from these chief producers, other

measures have been taken by WPB. It has sponsored Congressional appropriation of $1,000,000 and an equal expenditure by the United States Forest Service for the purpose of increasing production; backed efforts to make available prisoners of war to supplement the short labor supply; and instigated a campaign to encourage production of pulpwood by farmers and small holders of timber.

In the conservation program launched simultaneously with its salvage efforts, the Government recognizes two distinctly different contributions which the general civilian population and industry as such have to offer. The public as the prime user is in a position to effect the greatest saving of wrapping-paper tonnage. This can be accomplished if it is actively aware of the need for eliminating all unnecessary wrapping and is willing to accept unwrapped parcels and to use its own shopping containers whenever possible in its daily purchasing. Retailers naturally are loath to insist on this saving against customer opposition. A reduction of 25 per cent in the use of wrapping paper and bags by the public will mean an annual saving of over 250,000 tons of paper. As the main consumer of paperboard packaging and container material, industry has been requested to make its packaging wholly functional. Besides the over-all Government programs, many trade and industrial associations are conducting individual campaigns, and it is anticipated that a conservation of more than 750,000 tons of paper will result from these combined efforts. If the wood-pulp and waste-paper supply for the first quarter of 1944 is insufficient to support the production of enough paper and paperboard to meet all demands, the demand will be brought into balance with supply through limitation orders restricting consumption of paper and paperboard by the less-essential users.

WAR PROGRAM . . .

2,060-Mile Alaska Communication Line Now in Operation

A 2,060-mile communications line, linking the United States and Alaska by telegraph and telephone service along the entire length of the Alaska Military Highway, said to be the second longest carrier-communications system in the world, was completed in November 1943 and is now in operation.

The system, as well as the highway, was built in little more than a year by the United States Army Signal Corps, with the assistance of Bell System engineers, installers, and construction crews.

The first link from Edmonton, Alberta, to Dawson Creek, B. C., a distance of 442 lines, was started in November 1942. Five wire line groups from the American Telephone and Telegraph Company, Bell Telephone Company of Canada, and three other Bell System companies, together with a Signal Corps construction batallion of 140 men, working in temperatures ranging from 30 to 72 below zero, completed this section of the line and established communications by December 1, 1942.

The second link from Dawson Creek to Whitehorse in the Yukon Territory, covering a distance of 900 miles, was opened May 24, 1943. The third and final link, running some 650 miles from Whitehorse to Fairbanks, Alaska, was completed in November of 1943.

The complete 2,060-mile line carries two circuits which are expanded by *C*-type carrier systems so as to provide 7 talking channels and 14 teletypewriter circuits. Critical shortages of strategic metals made necessary the use of wire of only 30 per cent copper, which, however, was considered desirable because of the greater strength of the Copperweld wire. But to bring up the transmission conductivity it was necessary to use repeater stations every 95 miles instead of at the usual 200-mile interval.

The Alberta government telephone administration had previously attempted a radio link with the Yukon Territory, but "magnetic black-outs" made the attempt a failure. Atmospheric disturbances such as the Northern Lights interrupted radio transmission and reception during the winter days in the Arctic regions.

Latest Opportunities for Navy Commissions Listed

According to the latest Navy procurement bulletin, the opportunities for commissions and warrants, published in the December 1943 issue of *Electrical Engineering*, page 558, are still open to those qualified. The positions for which the number of candidates is still insufficient are: production expeditors, production analysts, inspectors of machinery, ship-repair engineers, naval academy instructors, antisubmarine engineers, and safety engineers. The requirements for an additional position for which some of our readers may be qualified follow:

S.P. 144-43 Job Analysis and Evaluation. Age 25 to 50. To be assigned to duty for the purpose of analyzing and evaluating civilian jobs and advising as to recruiting, placement, and classification of civilian personnel. Candidates must hold a degree from an accredited college and have had at least two years of recent intensive and progressively responsible experience in job analysis and evaluation work, or have had responsible administrative experience coupled with a thorough knowledge of job classification principles, regulations, methods, and problems. Preference will be given to those with a major in business administration or a background of engineering or accounting coupled with the foregoing experience. In the absence of a college degree, candidates must have had at least two years of college work and at least four years of the experience just described.

New Motor Designed to Increase Aircraft-Engine Production

An electric motor that revolves 1,000 times per second, said to be 20,000 rpm faster than any electric motor now being built for industrial use, has been developed by Robert M. Baker (M '40) Westinghouse Research Laboratories, to drive grinding wheels that put a mirror finish on hard-to-reach parts of airplane and tank engines and other war equipment. At present such grinders are powered by larger slower motors through belts and pulleys. The new motor will drive a grinder directly, eliminating production delays caused by breaking belts and increasing accuracy, often impaired by the sideward tug of the belt.

To meet the millionths-of-an-inch tolerance required in finishing aircraft-engine parts, the grinding wheel must cut effortlessly and smoothly, something that cannot be accomplished at low speeds. Many of these grinding wheels are less than an eighth of an inch in diameter, but they must attain high speeds at their grinding edge. Experience has shown that the best grinding speed is about a mile a minute on the face of the wheel.

Navy's Lamps Tested By Simulated Battle Blasts

No longer is it Navy shipboard routine to remove lamps from their sockets to stow them in safety before gunnery starts. The modern "rough service" lamps now in use on United States fighting craft are designed to withstand the concussion of heavy guns and permit interior quarters to remain lighted during an engagement.

The exceptional durability needed is assured in the plants of the Sylvania Electric Products, Salem, Mass., by testing the lamps on a "torture wheel" which reproduces the amount of shock to be sustained in service with the fighting fleet. Developed in line with the findings of the National Bureau of Standards, this wheel, about the size of an automobile wheel, is made of heavy steel with a ring of two dozen sockets in its outer rim. As it revolves, it drops spasmodically against a foil with a jar approximating a battleship's salvo. The lighted "rough service" lamps are maltreated in this fashion for from 3,800 to 7,600 poundings, depending on the wattage of the lamps.

Similar lamps are in demand for use on railroads, subways, and other places where heavy vibration and sharp shocks occur.

Sound-Powered Telephone Used for Combat Communications

A sound-powered telephone, operated without batteries and capable of carrying ten miles under favorable conditions, was used with great success on Guadalcanal, according to the War Department. Power in the telephone is generated by the human voice, and signaling is accomplished merely by whistling into the transmitter.

The equipment used on Guadalcanal was adapted to war communications by the Signal Corps from the commercially developed voice-powered telephone, and was installed on the island for fire control of infantry mortars and within infantry companies. It is smaller and more compact than battery-powered telephones and avoids the main disadvantage of these sets—deterioration of the batteries from the humidity and dampness of the South Pacific. Even under adverse conditions the set will carry messages five miles.

Periodicals Wanted for Foreign Libraries. A committee of the American Library Association is collecting scientific and technical journals for eventual shipment to foreign libraries and institutions unable to get them now because of the war. The committee is eager to acquire *Electrical Engineering*, and,

since the Institute has no stock of several issues published during the past year, only through your gifts can copies be obtained. The committee will provide storage space if necessary. If you wish to help by donating your periodicals, please write to Dorothy J. Comins, executive assistant, Committee on Aid to Libraries in War Areas, Library of Congress Annex, Study 251, Washington 25, D. C.

JOINT ACTIVITIES

ASA to Join Allied Nations Group Announced at Silver Anniversary

Participation by the American Standards Association in an Allied Nations Standards Body was authorized by the ASA board of directors at its silver-anniversary meeting in New York, N. Y., held in December 1943. The organization of such a body to secure maximum possible co-ordination of standards necessary for the war effort and the immediate postwar period has been discussed informally for some time between the British Standards Institution, the Canadian Engineering Standards Association, the ASA, and key governmental agencies in the three countries. It is planned that a skeleton staff will be provided for the new organization with offices in London and either New York or Washington, D. C.

Officers for 1944, announced at the meeting, are:

Henry B. Bryans, executive vice-president, Philadelphia Electric Company, *President elect.*

George S. Case, chairman of board, Lamson and Sessions Company, *re-elected vice-president.*

H. S. Osborne, chief engineer, American Telephone and Telegraph Company, re-elected *chairman*, Standards council, which is in charge of all ASA technical work.

E. C. Crittenden, assistant director, National Bureau of Standards, re-elected, *vice-chairman*, Standards council.

Speakers at the meeting included Percy Good, director of the British Standards Institution, who brought the greetings of his organization to the meeting; Clifton E. Mack, director of procurement, United States Treasury Department, in charge of Government lend-lease purchasing; R. E. Zimmerman, vice-president of United States Steel Corporation and retiring president of ASA, who spoke on postwar changes and developments in the use of Standards in the United States and in international trade; and H. S. Osborne (F '21) chief engineer, operation and engineering department, American Telephone and Telegraph Company, New York, N. Y., and chairman of the Standards council.

During the past year ASA has approved 119 Standards, and more new Standards have been issued during this year (93) than any other year. Seventy-five per cent of the Standards approved are classified as of direct value to the war effort: 25 per cent War Standards developed under the war emergency procedure, and 50 per cent permanent Standards. The remaining 25 per cent issued during the year are Standards approved in preparation for postwar activities.

During the year seven Standards have been approved and put to use covering various types of insulators, insulating material, and resistors. Fourteen additional Standards on this subject are under way.

One Standard, a specification for applying shock tests to electrical instruments, provides standard methods for testing electrical indicating instruments under conditions intended to simulate combat field conditions. Such tests are needed by the armed services for delicate electrical indicating instruments used in tanks and planes to insure that they will remain in service and give accurate results under the very severe conditions of combat.

A large amount of work was reported to have been done during the year by the committee on photographic Standards. This has included the adoption of a whole range of standard sizes for roll film and spools to produce the interchangeability required by the Armed Forces. The work also included Standards of rating of photographic speed and speed number for use in connection with the emergency photographic exposure guide developed last year at the request of the armed forces. Recently the War Production Board asked that specifications be developed for the various types of photographic and cinematographic equipment to be used by the Armed Forces. A war committee is already at work on this project.

The war has in many ways given a great impetus to the standardization movement by increasing the appreciation of the importance of standards, it was reported. A few months ago when the scarcity of critical materials was at its height the War Production Board issued a statement crediting the establishment of Standards with having saved 60,000 tons of steel and 17,000 tons of copper. Australia is using the American Standards for radio, and Canada has adopted eight of them. Australia, Canada, and Great Britain have adopted the American War Standards for Quality Control.

United Engineering Trustees, Inc., Elects Officers; Issues Report

At the annual meeting of the United Engineering Trustees, Inc., held October 28, 1943, the following officers for the year 1943–44 were elected: *president*, F. Malcolm Farmer (F '13); *first vice-president*, Arthur S. Tuttle; *second vice-president*, Charles E. Stephens (M '22); *treasurer*, Arthur S. Tuttle (re-elected); *assistant treasurer*, W. D. B. Motter, Jr. (re-elected); and *secretary* and *general manager*, John H. R. Arms (re-elected).

Members of the board of trustees of UET for 1943–44 are:

Terms expiring October 1944

Charles E. Trout, ASCE
W. D. B. Motter, Jr., AIME
Kenneth H. Condit, ASME
Everett S. Lee, AIEE

Terms expiring October 1945

A. L. Queneau, AIME
F. Malcolm Farmer, AIEE

Terms expiring October 1946

J. P. H. Perry, ASCE
Henry A. Lardner, ASME

Terms expiring October 1947

Arthur S. Tuttle, ASCE
Albert Roberts, AIME
George L. Knight, ASME
Charles E. Stephens, AIEE

Members of the finance committee are:

Charles E. Stephens, *chairman* — Henry A. Lardner
Arthur S. Tuttle — George L. Knight
Albert Roberts — F. Malcolm Farmer, ex officio

Members of the real estate committee are:

Charles E. Trout, *chairman* — Kenneth H. Condit
J. P. H. Perry — Everett S. Lee
A. L. Queneau — F. Malcolm Farmer, ex officio

Members of the executive committee are:

F. Malcolm Farmer, *chairman* — Henry A. Lardner
Charles E. Trout — Charles E. Stephens
Arthur S. Tuttle

United Engineering Trustees, Inc., was organized in 1904 to manage property and funds held jointly by the four national Founder Societies: American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers. The UET maintains two departments, the Engineering Societies Library and the Engineering Foundation, reports of which appear elsewhere in this issue. The corporation (UET, Inc.) manages the Engineering Societies Building and all trust funds placed with the UET, Inc.

ANNUAL REPORT

The annual report of UET, Inc., for the year 1942–43 has been submitted to the AIEE and other participating societies by Albert Roberts, president. Essential substance of the report follows.

The second year of the war has required readjustments in many of the operations of the corporation. Rising wage and materials costs in the case of UET have not been offset by increased income. On the contrary, it has been reduced by decreased use of meeting halls. Changes in the budget for the coming year have been made on the basis of a six-month thorough study of the possibilities of means of increasing income and effecting economies in operation.

The Engineering Societies Building has participated in the war effort by housing war agencies and by supplying a center for recruitment of engineer companies, and for lectures and classes in ordnance and other departments of the armed services. The office space in the building has been fully occupied for the entire year and, in one case, two meeting halls have been arranged for occupancy as office space "for the duration."

Operating expenses were sharply increased because of the higher wage rates for building-service employees ordered by the War Labor Board and the higher costs of maintenance materials. On the other hand, the income of the corporation has been reduced because of a continued decline in hall rentals; reservations for classes had to be cancelled when the students left the vicinity for war work or for the armed forces.

The net result of decreased income and increased costs was a deficit which would have been $11,270.24 had not the Founder Societies assumed responsibility for the greater part of this amount.

Insurance inspectors report that the building is in excellent physical condition. No major repairs or alterations were made during this past 37th year of use. In addition to the usual insurance carried on the property and on the Engineering Societies Library—namely fire, supplemental coverage, and liability and compensation insur-

ance—war-damage insurance was taken out again.

The annual audit shows the finances of UET to be in good condition. The corporation's portfolio is composed of trust funds amounting to $1,176,599.36, and a depreciation and renewal fund which has been accumulated over many years and which amounted to $474,544.11 at the end of the year. The fund was increased during the fiscal year by a total of $40,304.63, after receipt of the transfer from the building operations reserve of $20,000, as in years past, interest and dividends amounting to $16,655.70, and gains of $3,648.93 on reinvestment of capital funds.

The corporation acts as custodian for the funds of the John Fritz and Daniel Guggenheim Medal Boards, and other smaller funds, including contributions from industry to supplement the funds of The Engineering Foundation for research projects directed by them. Also, it continues as treasurer for the Engineer's Council for Professional Development.

Engineering Foundation Report Issued; Officers Elected

The following officers for the year 1943–44 were elected at the recent annual meeting of The Engineering Foundation, joint research agency of the Founder Societies: *chairman*, A. L. Queneau (re-elected); *vice-chairman*, Kenneth H. Condit; *director*, Edwin H. Colpitts; and *secretary*, John H. R. Arms. Members of the executive committee, in addition to the chairman, vice-chairman, and secretary of the Foundation are: J. P. H. Perry, W. I. Slichter (F '12), and Charles E. Stephens (M '22).

Members of the Foundation board for 1943–44 with the dates of expiration of their terms are:

Trustees elected by the board of trustees of UET, Inc.

Kenneth H. Condit, ASME, 1947
Charles E. Stephens, AIEE, 1947
A. L. Queneau, AIME, 1945
J. P. H. Perry, ASCE, 1944

Ex-officio, president, UET, Inc.

F. Malcom Farmer

Members nominated by Founder Societies

F. Malcolm Farmer, AIEE, 1947
Joel D. Justin, ASCE, 1947
A. A. Potter, ASME, 1947
F. F. Colcord, AIME, 1946
E. M. T. Ryder, ASCE, 1946
George D. Barron, AIME, 1944
Edwards R. Fish, ASME, 1944
W. I. Slichter, AIEE, 1944

Members-at-large

R. H. Chambers, ASCE, 1947
A. B. Kinzel, AIME, 1947
O. E. Buckley, AIEE, 1946

Members of the research procedure committee are:

Kenneth H. Condit, *chairman*, ASME
E. M. T. Ryder, ASCE
H. E. Wessman, ASCE
W. M. Peirce, AIME
W. Trinks, ASME
W. A. Lewis, AIEE

Chairman Queneau was appointed to represent the Foundation on the executive board of the National Research Council.

American-Built Generators Travel to Iceland

Final adjustments are being made here on the first of two 38-ton generators under construction at the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., which are destined for Iceland. This horizontal-type generator, which will supply power to cities as well as United States Army encampments, will add almost 3,000,000 watts to the island's electric output

The personnel of other committees as appointed or reappointed at this meeting is as follows:

Iron Alloys Committee

George B. Waterhouse, *chairman and director;* professor of metallurgy, Massachusetts Institute of Technology, Cambridge, Mass., AIME.

Lyman J. Briggs, director, National Bureau of Standards, represented by J. G. Thompson, senior metallurgist, National Bureau of Standards, Washington, D. C.

R. R. Sayers, director, United States Bureau of Mines, represented by R. S. Dean, assistant director, United States Bureau of Mines, Washington, D. C.

James T. Mackenzie, chief metallurgist, American Cast Iron Pipe Company, Birmingham, Ala., representing American Iron and Steel Institute.

John Johnston, director of research, United States Steel Corporation, Kearny, N. J., representing American Iron and Steel Institute.

James H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y., representing American Electrochemical Society.

Bradley Stoughton, professor emeritus, Lehigh University, Bethlehem, Pa., representing American Society for Metals.

Jerome Strauss, vice-president, Vanadium Corporation of America, New York, N. Y., representing American Society for Testing Materials.

T. H. Wickenden, assistant manager, development and research, the International Nickel Company, Inc., New York, N. Y., representing Society of Automotive Engineers.

Wilfred Sykes, president, Inland Steel Company, Chicago, Ill., member-at-large.

Frank T. Sisco, *consultant*, assistant secretary, AIME, New York, N. Y.

Welding Research Council

C. A. Adams, *chairman*, E. G. Budd Manufacturing Company, Philadelphia, Pa.

A. S. Albright, acting chief of research, Detroit Edison Company, Detroit, Mich.

David Arnott, vice-president, American Bureau of Shipping, New York, N. Y.

H. C. Boardman, *vice-chairman*, director of research, Chicago Bridge and Iron Company, Chicago, Ill.

Everett Chapman, P. O. Box 387—Coatesville, Pa.

O. U. Cook, assistant manager, department of metallurgy, inspection and research, Tennessee Coal, Iron and Railroad Company, Birmingham, Ala.

J. H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, New York, N. Y.

J. J. Crowe, assistant to vice-president and operating manager, Air Reduction Sales Company, New York, N. Y.

C. L. Ekergian, chief engineer, Budd Wheel Company, Detroit, Mich.

A. J. Ely, mechanical engineer, Standard Oil Development, Elizabeth, N. J.

F. H. Frankland, director of engineering, American Institute of Steel Construction, New York, N. Y.

T. S. Fuller, works laboratory, General Electric Company, Schenectady, N. Y.

Isaac Harter, vice-president, Babcock and Wilcox Company, Barberton, Ohio.

D. S. Jacobus, advisory engineer, 93 Harrison Avenue, Montclair, N. J.

G. F. Jenks, 232 Avondale Avenue, Los Angeles, Calif.

Carl M. Loeb, Jr., vice-president, Climax Molybdenum Company, New York, N. Y.

Arthur E. Pew, vice-president, Sun Oil Company, Philadelphia, Pa.

A. C. Weigel, vice-president, Combustion Engineering Company, New York, N. Y.

Clyde Williams, national defense research committee, Battelle Memorial Institute, Columbus, Ohio.

A. R. Wilson, engineer of bridges, Pennsylvania Railroad, Philadelphia, Pa.

R. E. Zimmerman, vice-president, United States Steel Corporation of Delaware, Pittsburgh, Pa.

W. Spraragen, *executive secretary*, Welding Research Council, 29 West 39th Street, New York, N. Y.

ANNUAL REPORT

The salient points of the annual report of the Engineering Foundation, as submitted by chairman A. L. Queneau to the AIEE and other Founder Societies at the meeting on October 21, 1943, follows.

The Engineering Foundation, which was established in 1914, completed its 29th fiscal year on September 30, 1943. The book value

of the capital funds of the Foundation on that date was $959,000, as compared with $952,000 on September 30, 1942. The income for the fiscal year 1942–43 was $35,160.38, as compared with $34,274.09 for the previous year. Disbursements amounted to $31,790.20, as compared with $31,430.36 for the year 1941–42. The balance on September 30, 1943, was $28,292.87, as compared with $24,922.69 on September 30, 1942.

It has been the policy of the Foundation for many years to contribute to a considerable number of projects in the diverse fields of engineering. In general, attempt is made to select projects of a fundamental type which normally would not be undertaken by industrial research organizations. In certain other cases the Foundation serves as a catalyzing agent, so to speak, for projects which are largely supported by contributions from industry. This policy of the Foundation has been continued for the year 1942–43, but the projects have been scrutinized with regard to their bearing on the war, and have been encouraged only insofar as they appeared to contribute to the war effort.

Because of the Government's willingness to support research projects demonstrated as important to the war effort, and because of the withdrawal of research personnel to more direct war activities, the immediate demands upon the Foundation's income for the support of research projects helpful to the national cause seem likely to decrease. However, in the years following the war, it is certain that engineering research in many fields should be encouraged and expanded. Consequently, in those years the Foundation could doubtless employ a much larger income than almost surely will be available from its present capital funds.

During the year, work on 14 projects has continued. For the ensuing year, grants were recommended for continuation of work on six projects and the initiation of one new project.

Summaries of the research projects which were sponsored by the Foundation and with which AIEE has been associated directly follow:

Insulation Oils and Cable Saturants. (Foundation grant, $1,000. Chairman, Herman Halperin, assistant equipment and research engineer, Commonwealth Edison Company, Chicago, Ill.)

This project, which has been supported in part by the Foundation for a number o years, concerns the stability of insulating oils in power cables and other electrical apparatus. An important feature of the work during the fiscal year 1942–43 were the studies on factors influencing the electrical stability of mineral oils under limited-oxidation conditions. These limited oxidation conditions are particularly important in the practical application of oilpaper insulation. Whereas a complete solution of the problem has not been attained, several factors influencing this stability have been determined, and complete systems of test and equipment have been developed.

The effect of oxidation inhibitors and other additives on the electrical stability of mineral oils under limited oxidation has been studied, also, as has the effect of percentage of aromatics. This latter has been studied by blending cuts of an oil having different degrees of aromaticity. The effect of variable temperature has been observed in limited-oxidation studies. Tests have been made over a temperature range from 85 to 145 degrees centigrade. These tests were made with both oil and oilpaper in contact with copper. Furthermore, these variable-temperature tests have been made with different amounts of available oxygen.

Studies were made, also, on the effect of different degrees of refining on limited oxidation. Oils for this purpose were supplied by the Sun Oil Company, and consisted of samples having four different degrees of refining treatment, one of the intermediate ones being the normal or conventional amount. Service-aged and specially processed oils supplied by contributing companies were subjected to various tests.

During the past year, two papers were prepared in connection with this project. The first of these was "Mineral Insulating Oils—Effect of Additives on Electrical and Chemical Stability," by A. G. Assaf and J. C. Balsbaugh (*Industrial and Engineering Chemistry*, volume 35, August 1943, pp. 909–16). "Electrical Stability of Electrical Insulating Oils Under Limited Oxidation," by J. C. Balsbaugh and A. G. Assaf, was presented before the winter technical meeting of the AIEE, New York, N. Y., January 1943, and became available to the industry the first of the present fiscal year.

The advisory committee for this project held two meetings during the past year, on September 28, 1942, and on January 25, 1943. At the second meeting the committee members agreed that the research, in spite of its value and promises, should not be continued beyond August 31, 1943, unless it could be shown that the activities had become directly concerned with the war effort. As no such special problems developed, the committee recommended suspension of the project as of August 31, 1943, with the consideration that it might be desirable to resume it after the war.

Welding Research Council. (Foundation grant $4,000. Chairman, Comfort A. Adams, E. G. Budd Manufacturing Company, Philadelphia, Pa.)

About January 1, the Welding Research Committee was completely reorganized and renamed the Welding Research Council. This reorganization was undertaken to bring about a simplification of structure and to enable the Welding Research Council to carry on its activities more closely with the war effort. Some committees were discontinued for the duration of the war and the work formulated under the following project committees. Duplication of effort and red tape, in the opinion of the Council, have been eliminated almost completely.

Aircraft welding research committee
Fatigue-testing (structural) committee
High-alloy steels
Light alloys
Literature committee
Nickel alloys
Resistance welding
Structural steel committee
University research committee
Weldability
Weld-stress committee

Under cognizance of these committees, studies and investigations of broad scope relating to many phases of welding have been continued. Co-operation with the aircraft industry has been maintained, in part at least, through the National Advisory Committee for Aeronautics. Various research projects started under the university research committee have been taken over and largely expanded by the National Defense Research Committee.

As to publications, during the year 620 (9 by 12) printed pages were published covering approximately 79 reports on almost every phase of welding.

LIBRARY

OPERATED jointly by the AIEE and the other Founder Societies, the Engineering Societies Library, 29 West 39th Street, New York 18, N. Y., offers a wide variety of services to members all over the world. Information about these services may be obtained on inquiry to the director.

Board and Officers of Library Elected; Annual Report Issued

At the recent annual meeting of the Engineering Societies Library board, W. A. Del Mar (F '20) was reappointed chairman for 1943–44 and W. D. B. Motter, Jr., was appointed vice-chairman. Harrison W. Craver was reappointed director of the Library and secretary of the board.

Members of the library board are as follows:

Terms expiring October 1944

J. K. Finch, ASCE
James W. Laist, AIME
A. R. Mumford, ASME
W. A. Del Mar, AIEE

Terms expiring October 1945

Edward P. Hamilton, ASCE
W. A. Mudge, AIME
John Blizard, ASME
W. I. Slichter, AIEE

Terms expiring October 1946

Charles E. Trout, ASCE
Thomas T. Read, AIME

Terms expiring October 1947

E. F. Church, Jr., ASME
George L. Knight, AIEE

Members at Large

George F. Felker
Sydney H. Ball
Robert H. Barclay

Members of the executive committee for 1943–44 are:

E. F. Church, Jr. — G. L. Knight
E. P. Hamilton — T. T. Read

ANNUAL REPORT

The annual report of the Engineering Societies Library for the year 1942–43 has been submitted by Harrison W. Craver, director, to the AIEE and other Founder Societies. Essential substance of the report follows.

The past year in the library has been a constant scramble to keep up with the flood of inquiries from members engaged in war work and from departments of the Government, all of whom wanted definite information upon details of manufacturing processes, upon foreign factories, docks, public works, and other matters of military significance. All this information was wanted immediately. Much of it was too novel to have appeared yet in print to any great extent.

Operation of Library

Maintenance revenue	$49,393.62	
Maintenance expenditures	42,642.25	
Credit balance for year 1942–43	6,751.37	
Credit balance from previous years	11,382.79	
Credit balance September 30, 1943		$18,134.16
Service bureau revenue	$14,415.24	
Service bureau expenditures	11,162.64	
Credit balance for year 1942–43	3,252.60	
Credit balance from previous years	4,974.88	
Credit balance September 30, 1943		8,227.48
Total net operating credit balance cumulated to September 30, 1943		$26,361.64

The year's experience has proved the soundness of the book collection. The small collection of Japanese books and periodicals in the library has proved to be the most extensive in the country, and the collection of German works has seldom failed to produce the book desired. The library has lent a number of these to publishers who were authorized by the Alien Property Custodian to reproduce them. The large resources of the library in older works and in files of foreign magazines have proved invaluable in providing material.

As a result, the collection has been used extensively by the Army and the Navy. Certain of their researchers arrive as soon as the library opens in the morning and work throughout the day. Others come regularly from Washington, D. C., and other centers to search the files. The war has created a growing appreciation of the value of reference libraries as storehouses of knowledge. The necessity for building them up in advance of need has become apparent as never before.

Service to the Government has not ended with provision of books. One assistant was lent to the Army Corps of Engineers for seven months, during which time she organized its cataloguing and indexing service upon a satisfactory basis. Another was released for several days a month to act as consultant to the Signal Corps in building up a reference library in Washington, D. C. In addition, the staff as a whole constantly has been giving freely of its experience and knowledge as occasion arose.

Whereas the library was used by more people than in the previous year, the increase was the result of greater use by mail by nonresident members rather than by a greater number of visitors to the library itself. The number of visitors was 22,260, as compared with 23,734 in 1941–42, and 13,579 others have made use of it in other ways, as compared with 10,648 for that year. Total number of users of the library was 35,839 for 1942–43, and 34,382 for the preceding year.

The greatest increase in service was in calls for photostats. This year 3,487 orders for photostats and microfilms were received, an increase of 15 per cent. The number of prints made was 38,702, an increase of 23 per cent.

Telephone inquiries numbered 6,689, an increase of 10 per cent. The number of borrowers was 1,055, an increase of 62 per cent, to whom 1,393 books were lent. Letters were written to 2,232 members, answering questions that did not call for sustained searching. This represented an increase of 30 per cent over the preceding year. In addition, 86 searches and 30 translations were prepared.

The fact that the 13,579 persons who used the library without visiting it constituted 38 per cent of the users is gratifying, and shows the extent to which the membership at large is using the collection.

On December 26, 1942, W. S. Barstow (F '12), for many years a member of this board died. Mr. Barstow's interest in the library was deep and had been manifested on many occasions by generous gifts, among them being one of several thousand dollars to repair and restore the bindings of the rare book collection. He also left a bequest of $10,000 to the library. His wise counsel and pleasant personality will be sadly missed by the board and the director.

The library suffered another severe loss, on September 13, 1943, through the death of Harrison A. von Urff. For seven years Mr. von Urff had been in charge of bibliographic work. During that time hundreds of members had learned to know his great skill in locating printed information, and to admire his modesty and quiet helpfulness. His unusual talent for this work will be hard to replace.

The tendency toward reduction in book output, which was noted in the preceding report, has continued. The technical publishers have been kept busy by the demands of the Army and Navy for enormous numbers of elementary textbooks for training the forces. In addition, most engineers who would normally be writing are too busy to do so. The scarcity of paper and binding materials, plus the impossibility of getting European books, has resulted in fewer books being added to the library. Whereas 10,286 books and pamphlets were received—almost as many as in the preceding year—only 2,010 of these were adjudged worthy of permanent preservation, as compared with 5,523 in that year. This reduction reflects the effect of the war upon technical publication.

During the year the staff reviewed 420 books for the periodicals of the Founder Societies.

At the end of the year the library contained 156,780 volumes, 7,872 maps, and 4,565 searches, a total of 169,216 items.

As in former years, the library has been the constant recipient of gifts from members and friends. To mention all of these in detail is impracticable, but a few of unusual extent may be noted.

The estate of John R. Freeman presented the major portion of Mr. Freeman's professional library, consisting of thousands of reports and books collected during a long, busy life and covering the varied branches of civil engineering in which he had been eminent. Other important gifts included a large collection of periodicals from Pope Yeatman, another from Mrs. C. Minot Weld, and a third from Charles N. Green. George H. Gibson presented a useful collection of American and German periodicals. Ernest P. Goodrich also added materially to our resources, as did Spencer, White and Prentis; T. G. Townsend; and Joseph Meltzer. The McGraw-Hill Book Company, Inc., presented many hundreds of books which had come to its editorial offices for review purposes.

To these and other donors our hearty thanks are given.

The budget established for general operation was $50,000, of which the following amounts were provided by the Founder Societies, on a membership basis:

American Society of Civil Engineers	$10,132.10
American Institute of Mining and Metallurgical Engineers	8,227.10
American Society of Mechanical Engineers	9,471.20
American Institute of Electrical Engineers	10,501.70
	$38,332.10

Expenditures from this budget amounted to $42,642.25 of which $6,442.75 was spent for books, periodicals and other equipment of permanent value. Service Bureau receipts for special service were $14,415.24 and its expenses were $11,162.64.

INDUSTRY

Sylvania Increases Electronics Output With New Gas Plant

A new electrolytic plant at Williamsport, Pa., costing in excess of $150,000 and equipped with 108 electrolytic cells, high-powered compressor machines, low-pressure and high-pressure storage tanks, and a water distillery, which will furnish hydrogen and oxygen for tube makers in the Williamsport and Towanda, Pa., factories, has just been completed by Sylvania Electric Products Inc.

"Consuming a gallon of water per cell per hour, our generator will produce 2,000 cubic feet of hydrogen and half as much oxygen per hour," said Bruce Goldsmith, manager of the plant. The storage tanks contain water which is broken down by a direct current of 1,200 amperes at 150 volts. Each cell has two compartments, one containing the electrode that liberates hydrogen, the other containing the oxygen electrode. The gas rises and is carried away by a system of pipes overhead, goes to low-pressure tanks, and later is compressed to 300 to 2,500 pounds pressure.

Lightning Frequency Registered by Plastic Device

Perfection of a counting device which will point out vulnerable spots requiring protective arresters by recording data on the frequency of lightning strokes along transmission systems, has been announced by

Doctor Leo Finzi (A '40) research engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

About the dimensions of a playing card, the counter consists of two strips of metal foil enclosed between two pieces of transparent plastic material. One foil strip is edged with teeth which are a few thousandths of an inch from the straight edge of the second strip. When lightning strikes a power line, a small part of the current is sidetracked into the saw-toothed strip and must jump to the straight-edged strip to reach the ground. Taking the easiest path—the tooth whose tip is nearest the straight-edged strip—the current closes this gap and makes a tiny spark which scorches a black spot on the plastic and burns away the tip of the tooth, so that the next discharge must follow another path. Since no two of the gaps between the strips are exactly the same, one path is always easiest for the current, and the counter never misses recording a stroke of lightning. As soon as the spark occurs, the voltage in the strip drops and another spark will not occur until lightning strikes again which obviates the possibility of one lightning stroke's being recorded more than once. The device easily can be fastened near the bottom of a power-line tower so the blackened dots on it can be counted in a few seconds.

OTHER SOCIETIES •

ICI Program Promotes Advances in Heating and Cooling

Organization of the Indoor Climate Institute, an industry-wide co-operative educational program for the improvement of heating, cooling, and air conditioning, has been announced by Paul B. Zimmerman, president. A board of directors, and advisory council, and executive officers have been elected, and headquarters have been established at Detroit, Mich.

Sponsored by leading manufacturers of heating, cooling, and equipment industries, suppliers of controls and accessories, and producers of major heat conservation materials, the Institute will serve as a clearinghouse of information. The technical committees of the ICI will make a study of the codes, standards, and practices as established by the various industry trade associations and authorities for the benefit of the public, and will co-operate with manufacturers and trade associations in developing potential markets.

New Association Organized by Corrosion Engineers

A new organization to be known as the National Association of Corrosion Engineers is being formed by the Mid-Continent Cathodic Protection Association, and all persons engaged in the work of corrosion control or mitigation on underground metallic structures are invited to apply for membership. Inquiries should be directed to O. C. Mudd, acting secretary-treasurer, care of Shell Pipe Line Corporation, Box 2648, Houston 1, Tex., or to R. A. Brannon, acting president, care of Humble Pipe Line Company, Drawer 2220, Houston 1, Tex. The new group plans to hold an annual meeting April 10, 11, and 12, 1944, at the Rice Hotel, Houston, to which all members or applicants for membership are invited.

The Mid-Continent Cathodic Protection Association, formed in 1938 for the purpose of exchanging information regarding developments in the field of mitigation or prevention, by electrical means, of corrosion to pipe lines and other metallic structures, has been meeting and carrying on its work as the cathodic section of the Petroleum Industry Electrical Association. The group is also interested in the promotion of co-operative action between companies or organizations and the development of standard procedures and methods for use in connection with corrosion control.

Future Meetings of Other Societies

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 20–24, 1944, New York, N. Y.

American Society of Civil Engineers. January 19–21, 1944, New York, N. Y.

American Society of Heating and Ventilating Engineers. 50th annual meeting, January 31–February 2, 1944, New York, N. Y.

American Society of Mechanical Engineers. Spring meeting, April 3–5, 1944, Birmingham, Ala. Semi-annual meeting, June 19–20, 1944, Pittsburgh, Pa.

Engineering Institute of Canada. Annual meeting, February 1–11, 1944, Quebec, Que.

National Electrical Manufacturers' Association. April 23–7, 1944, Chicago, Ill.

National Fire Protection Association. May 8–11, 1944, Philadelphia, Pa.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Voltage Drop Through the Armature Circuit

To the Editor:

A common method of determining the internal resistance of a battery is to load the battery through two different values of external resistance. The internal resistance of the battery is then calculated from the equation:

$$R = \frac{(E_1 - E_2)R_1R_2}{E_2R_1 - E_1R_2} \text{ or } \frac{R_1I_1 - R_2I_2}{I_2 - I_1}$$

The determination of the internal resistance of the armature circuit of a d-c motor or generator under operating conditions offers an analogous problem and suggests the application of a similar solution. The voltage relations in a motor are expressed by

$$V = E + RI = K\phi S + RI$$

where

V is the applied terminal voltage.
E is the counterelectromotive force of the motor and equals $K\phi S$.
K is a constant depending upon the construction of the machine.
ϕ is the flux cut by the armature conductors and may be made constant if the field current and armature-ampere turns are maintained constant.
S is the speed of the armature.
R is the internal resistance of the armature, and includes the copper resistance of the winding and the contact drop between the brushes and the commutator.
I is the armature current.

The copper resistance of the armature may be measured satisfactorily at standstill, but it is questionable as to whether the contact drop at standstill is the same as under running conditions.

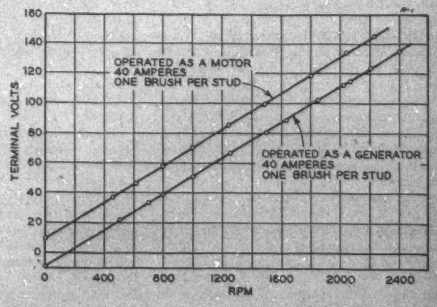

Figure 1

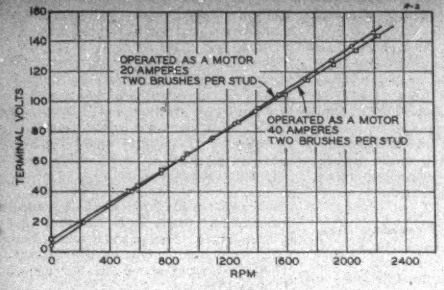

Figure 2

If the motor is run with a known resistance R_2 in series with the armature circuit and at the same time the load is adjusted to maintain a constant armature current a second speed is observed.
Then

$$V = kS + RI$$

and

$$V = kS_2 + (R_2 + R)I$$

where

$$k = K\phi$$

since ϕ is constant
Hence

$$R = \frac{V}{I} - R_2 \frac{S}{S - S_2}$$

Since the solution involves using the difference of two speeds, it does not lend itself to a high degree of accuracy. In place of using an auxiliary external resistance, equally good results can be obtained simply by applying more than one voltage at the terminals of the brushes while maintaining the armature current and field excitation constant.

$$V = kS + RI$$

It is noticed that this relation is a straight line, if the value of R, that is the copper and contact drop, remains constant with change of speed. If projected to the ordinate of zero speed, it gives the armature-circuit voltage drop.

An experimental run, using a five-kilowatt generator gave the results shown in Figures 1 and 2. The curves show that within the limits of experimental error the drop through the armature circuit while running is the same as the drop at standstill provided the standstill drop is measured immediately after the machine is shut down and while the brushes are still hot.

It is conceivable that the contact drop might vary proportional with the speed and thus make the above equation a straight line. To test this, the machine was run as a generator, resulting in another straight line which is substantially parallel with the motor line, indicating that the contact drop is constant.

A run made with half the brushes removed, doubling the current density, brings out the increase in contact drop with increase in current density.

For any particular value of field current the slope of the straight line curve gives the value of k in the equation:

$$V = kS + RI$$

The plot of the data obtained by runs made with a constant field current and three values of armature current, 20, 30, and 40 amperes, brings out the fact that the field flux is dependent upon both the field ampere turns and the armature ampere turns, as each value of armature current gives its corresponding value of k, run as a motor, the larger values of armature current give smaller values of k, that is, smaller values of ϕ, and greater speed of the motor for any given value of counterelectromotive force.

H. S. RUSH (M '30)

(Assistant dean, school of engineering and professor of electrical engineering, North Dakota Agricultural College, Fargo)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in the columns should be addressed to the publisher of the book in question.

Descriptive Geometry for Engineers. By H. C. Bradley and E. H. Uhler. Second edition. International Textbook Company, Scranton, Pa., 1943. 266 pages, illustrated, 9 by 6 inches, cloth, $2.50.

Problems in Descriptive Geometry for Engineers. By E. H. Uhler. International Textbook Company, Scranton, Pa., 1943, no pagination, illustrated, 9 by 12 inches, paper, $1.75. (ESL.)

Part I of this text deals with fundamental principles, covering projections, constructions, surfaces, intersections, methods of revolution, and the method of traces. Part II describes the application of these principles to engineering problems: civil, mechanical, chemical, mining, and structural geology.

The text is supplemented by a separate book of plates containing problems to be solved by both graphical and mathematical methods. Plates are numbered to refer to chapter and article of the explanatory text.

Engineering Encyclopedia. Edited by F. D. Jones. 2 volumes. Second edition. Industrial Press, New York, N. Y.; Machinery Publishing Company, Ltd., Brighton, England, 1943. 1,431 pages, illustrated, 9½ by 6 inches, fabrikoid, $8. (ESL.)

This two-volume reference work supplies such practical and useful engineering information as the various important mechanical laws, rules, and principles; physical properties and compositions of a large variety of materials used in engineering practice; the characteristic features and functions of different types of machine tools and other equipment; and so forth. The 4,500 topics included are alphabetically arranged and cross-indexed for convenient reference, and have been selected for their usefulness in the mechanical industries.

How to Maintain Electrical Equipment. General Electric Company, Schenectady, N. Y., 1943. 372 pages, illustrations, 8¼ by 10½ inches, $1.75.

To help industrial plants secure maximum performance and length of service from electrical equipment, the General Electric Company has prepared this volume of general suggestions for maintenance engineers. Among others, sections are devoted to battery trucks, cable and wire, Diesel-electric locomotives, electric furnaces, fuse cutouts, industrial control, lighting, motors and generators, rectifiers, switchgear, transformers, and welders. Each section contains a preventive-maintenance chart and a trouble-shooting chart. Numerous diagrams and pictures supplement the text.

Mathematischen Hilfsmittel des Physikers (Mathematical Tools for the Physicist). By E. Madelung, K. Boehle, and S. Flügge. Third edition; published and distributed in the public interest by authority of the Alien Property Custodian under license A-146; American edition, Dover Publications, New York, N. Y., 1943. 384 pages, illustrated, 9½ by 6 inches, cloth, $3.50. (ESL.)

The purpose of this book is to provide for physicists a concise statement of those parts of mathematics that are of direct use to them, and which otherwise could be obtained only by consulting a large variety of textbooks. The first section is devoted to mathematics; the second to physics. This American edition is a photographic copy of the German edition of 1935, offered at about one third the former price.

Water Power Engineering. By H. K. Barrows. Third edition. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 791 pages, illustrated, 9 by 6 inches, cloth, $6. (ESL.)

The whole field of water-power development for hydroelectric purposes is covered in this standard textbook. Beginning with hydrology and the study of stream-flow data it continues through the construction and operation of dams, canals, and penstocks to a discussion of the powerhouse and its equipment. There are chapters on turbine regulation and on transmission lines. The cost and value of water power are discussed, and typical installations are described briefly.

Diesel Engineering Handbook. 1943 de luxe edition. Originally edited by L. H. Morrison, revised by C. F. Foell. Diesel Publications, New York, N. Y. 966 pages, illustrated, 9½ by 6 inches, cloth, $7. in United States; $8. in foreign countries. (ESL.)

Practical, up-to-date information, valuable both to the owner and operator, is provided upon the operation and maintenance of Diesel engines. The treatment is exhaustive, and the book is illustrated profusely from actual practice. Two chapters of engineering fundamentals are devoted to brief description of useful general engineering terms and equipment.

Graphical Construction for Vacuum Tube Circuits. By A. Preisman. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 237 pages, illustrated, 8½ by 5½ inches, cloth, $2.75. (ESL.)

This book is concerned mainly with the graphical methods by which solutions to problems on nonlinear circuits, particularly those involving vacuum tubes are obtained. Special attention is paid to those problems which are not amenable to the analytical method, but others are included which utilize a combination of the two methods. Much of the material is a revision of magazine articles previously published by the author.

Fundamentals of Optical Engineering. By D. H. Jacobs. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 487 pages, illustrated, 8½ by 5 inches, cloth, $5. (ESL.)

By providing an introductory text which gives attention both to optical and mechanical design, this book fills a gap in the literature on optical instruments. The fundamentals of optics are set forth first, and followed by descriptions of such representative instruments as telescopes, periscopes, gun sights, and range finders. Following this, the mechanical, electrical, and optical design of instruments is discussed.

Encyclopedia of Substitutes and Synthetics. Edited by M. D. Schoengold. Philosophical Library, New York, N. Y., 1943. 382 pages, tables, 9½ by 6 inches, cloth, $10. (ESL.)

This encyclopedia covers products that have been developed recently in order to replace critical materials that have become difficult or impossible to obtain. The properties and uses of these replacement materials are given; the materials needing to be conserved are listed with their practical substitutes; and a separate index of trade names is provided. All branches of industry, manufacture, and pharmaceutics are represented.

Electroplating. By S. Field and A. D. Weill. Fourth edition revised and enlarged. Sir Isaac Pitman and Sons, London, England; Pitman Publishing Corporation, New York, N. Y., 1943. 437 pages, illustrated, 7½ by 5 inches, cloth, $5; 15s. (ESL.)

The major part of this text is devoted to description of the practical processes by which metals are deposited on a surface. Fundamental principles are discussed briefly; the electroplating plant is described; mechanical and chemical cleaning of metals is covered; and chapters are included on the testing of electrodeposits and on metal coloring.

Fundamentals of Engineering Drawing. By W. J. Luzadder. Prentice-Hall, Inc., New York, N. Y., 1943. 568 pages, illustrations, etc., 9½ by 6 inches, cloth, $4. (ESL.)

The early chapters of this comprehensive work present simple instructions about necessary equipment and its use, and deal briefly with engineering geometry and the fundamentals of drawing technique. In the later chapters, detail work and the making of drawings for various engineering operations and other special purposes are described. A chapter on engineering graphs, charts, and diagrams is included.

Cellulose and Cellulose Derivatives. (High Polymers, volume 5.) Edited by E. Ott. Interscience Publishers, New York, N. Y., 1943. 1176 pages, illustrated, 9½ by 6 inches, cloth, $15. (ESL.)

Thirty-six well-known workers have contributed to this monograph, which is intended to present "the most important modern scientific and technical information concerning cellulose and its derivatives and to have this information in such form that it becomes a thorough introduction for work on any cellulose problem by any person having reasonably wide general technical training."

Principles of Physical Metallurgy. By F. L. Coonan. Harper and Brothers, New York, N. Y., and London, England, 1943. 238 pages, illustrated, 9½ by 6 inches, cloth, $3.25. (ESL.)

The fundamentals necessary for a general appreciation of the properties of metals and alloys are presented in this brief elementary text intended for students who require a knowledge of the nature and characteristics of the metals and alloys of commercial importance. The first section presents physical principles. The succeeding two sections deal respectively, with nonferrous alloys and alloys of iron and carbon.

Heat and Thermodynamics. By M. W. Zemansky. Second edition. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 390 pages, illustrated, 9 by 6 inches, cloth, $4. (ESL.)

This intermediate textbook for students of physics, chemistry, and engineering, discusses in the first half the fundamental ideas of heat, ideal gases, reversibility, entropy, and so forth. The remaining chapters deal with physical, chemical, and engineering applications in sufficient detail to show how the general principles are applied to specific cases.

Mineral Resources of Africa. (African Handbooks: 2.) By A. W. Postel. University of Pennsylvania Press, Philadelphia, 1943. 105 pages, illustrated, 8½ by 5½ inches, paper, $1.50. (ESL.)

The available data on the mineral resources of Africa and their development; current production, reserves, and so forth, are summarized concisely in this pamphlet. The annual world production and the annual production of the chief producer of each mineral are given for comparison. The work affords a convenient survey of Africa's position in the mineral industry.

Elements of Electrical Circuits and Machinery. By G. C. Blalock. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1943. 347 pages, illustrations, etc., 8 by 5½ inches, cloth, $3. (ESL.)

This textbook is intended for brief courses in circuit theory and the practical applications of electrical equipment and is adapted for use in technical high schools and trade schools. Mathematics is used sparingly and all references to calculus and differential equations are omitted. A list of laboratory experiments is included.

Experiments in Electronics and Communication Engineering. By E. H. Schulz and L. T. Anderson. Harper and Brothers, New York, N. Y., and London, England, 1943. 381 pages, illustrations, etc., 9½ by 6 inches, cloth, $3. (ESL.)

This laboratory guide has been prepared for use in training men for the Signal Corps of the United States Army. It is intended to serve courses at college level in electronics, communication networks, radio, and ultra-high-frequency phenomena. Over 100 experiments are given, with discussions of principles and directions.

Geology of Kentucky. By A. C. McFarlan. University of Kentucky, Lexington, 1943. 531 pages, illustrated, 9½ by 6 inches, cloth, $4.50. (ESL.)

This work is a revision of Arthur M. Miller's "Geology of Kentucky," long out of print. The literature on the stratigraphy, regional geology, and mineral resources of the state is summarized thoroughly. An extensive bibliography is included.

PAMPHLETS

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Electronics in Industry. RCA Victor Division of the Radio Corporation of America, Camden, N. J., 44 pages, no charge.

Ignitron Mercury-Arc Rectifiers. General Electric Company, Schenectady, N. Y., 36 pages, no charge.

Facts About Synthetic Rubber. New York Belting and Packing Company, 1 Market Street, Passaic, N. J., 32 pages, no charge.

Packaging, Marking, and Loading Methods for Steel Products for Overseas Shipments. American Iron and Steel Institute, 350 Fifth Avenue, New York, N. Y., 215 pages, $2.50.

Postwar Employment and the Settlement of Terminated War Contracts. The Committee for Economic Development, Room 3311, Department of Commerce Building, Washington, D. C., 15 pages.

Your Business After the War. Research Institute of America, 292 Madison Avenue, New York 17, N. Y., 61 pages, $2.

Membership List and Trade Directory. Radio Manufacturers Association, 1317 F Street, N. W., Washington 4, D. C., 47 pages.

Accident Rates in the Public Utility Industries, 1942. National Safety Council, Inc., 20 North Wacker Drive, Chicago 6, Ill., 24 pages, 20 cents.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the June 1944 Supplement to Electrical Engineering—Transactions Section

Study of Artificial Respiration on Anesthetized Men

W. B. KOUWENHOVEN
FELLOW AIEE

D. R. HOOKER
NONMEMBER AIEE

J. A. YORK
NONMEMBER AIEE

IN an earlier paper[1] the authors reported the results of a study of the methods of artificial respiration when conscious subjects were used. In that study three methods of artificial respiration were investigated: namely, the Schafer prone-pressure method, the modified prone-pressure method, in which the hands were rolled or snapped off the subject's back, and the pole-top method.[2] A total of 15 men was tested, and the volume of air moved by the three methods of artificial respiration was measured. All of these men were conscious, and the results indicated that all the methods were adequate, with the pole-top method in the lead. Although all of the subjects were intelligent and presumably capable of completely relaxed passivity, such results are always open to the criticism that the subject may have co-operated, perhaps unintentionally.

The investigation was, therefore, repeated, using anesthetized subjects in whom there is no possibility of co-operative aid. One of the barbiturates, sodium pentothal, was administered intravenously. This drug promptly effects unconsciousness and complete muscular relaxation. At the outset it depresses the respiration, which quickly assumes a comparatively steady state. This can be maintained safely for a considerable period of time by the judicious administration of repetitive doses of the drug. Subjects *A*, *B*, and *C* were studied and were carried through the procedure successfully.

Paper 44-22, recommended by the AIEE committee on safety for presentation at the AIEE winter technical meeting, New York, N. Y., January 24-28, 1944. Manuscript submitted August 11, 1943; made available for printing November 24, 1943.

W. B. KOUWENHOVEN is dean of the school of engineering; D. R. HOOKER is in the school of hygiene and public health; and J. A. YORK is in the department of surgery, all in the Johns Hopkins University, Baltimore, Md.

Experimental Procedure

The subject's breathing was first measured while he was in a conscious state. A mask was placed firmly over his nose and mouth and connected to a spirometer (gas meter) which measured the volume of air breathed. A pneumograph was placed around the chest to ascertain the amount of chest expansion and contraction. A revolving smoked drum recorded the amount of air passing through the gas meter, the chest movement, and the time. The data thus secured served to determine the amount of air breathed in the unit of time necessary to complete the experiment.

The subject then placed himself in a prone position on a mat lying on the floor. After five minutes had been allowed for him to relax, a record of his natural breathing was taken. A trained operator then gave him artificial respiration, employing the standard Schafer method, and then after a suitable interval, the modified Schafer method. The conscious subject, with the mask still in place, climbed a pole that was mounted in a laboratory, and seated himself astride the safety strap of the operator. His position on the pole was similar to that of a lineman who had received a shock, except that his feet were only about one foot above the floor. The subject's natural breathing was recorded, and then the operator applied the pole-top method of artificial respiration.

The anesthetic was then administered to the subject while he was still on the pole and astride the operator's safety strap. The subject became unconscious quickly, and, after the elapse of a few minutes, his breathing reached a steady state. This was recorded. Then artificial respiration was administered by the operator, using the pole-top method.

When this was completed, the subject was lifted down from the pole, while still in an unconscious state, and placed in a prone position on the mat. The gas mask was not disturbed in this operation. The subject's natural breathing in this prone position and unconscious state was recorded. Then the operator applied artificial respiration by the standard and modified methods in turn. When the experiment had been completed, the administration of the anesthetic was stopped, and the gas mask and pneumograph were removed. The subject was made comfortable and allowed to rest until he was fully conscious. None of the subjects experienced ill effects from the procedure.

Pauses of several minutes were interspersed between each operation in order that the subject's respiration might become normal under the existing conditions before the next step of the experimental procedure. The results obtained in an experiment of this character are not strictly comparable to what might be expected in individuals in which all respiratory activity has ceased, but they probably are as close as laboratory conditions can provide.

The data taken are presented in Table I. It will be noted that the imposed respiratory rate during artificial respiration is less than in natural breathing. This is particularly true of the subjects when they are in an unconscious condition. The amount of air moved per respiration is, however, considerably greater. It is thus evident that all three methods of artificial respiration are more than adequate to supply the necessary ventilation of the lungs. In the last column of Table I the average results reported on the 15 conscious subjects in the earlier paper[1] are given for the purpose of comparison.

In Table II the data are expressed as

Table I

Conditions	A 22 Years 139 Pounds	B 38 Years 160 Pounds	C 38 Years 167 Pounds	Average A, B, C	Average 15 Subjects
Conscious					
Natural breathing in prone position					
Respirations per minute	15	14	11	13	13
Cubic centimeters per respiration	375	625	770	590	545
Cubic centimeters per minute				7,670	7,090
Original Schafer artificial respiration*					
Respirations per minute	14	10	12	12	11
Cubic centimeters per respiration	424	1,000	1,111	845	868
Cubic centimeters per minute				10,150	9,540
Modified Schafer artificial respiration**					
Respirations per minute	13	11	10	11	11
Cubic centimeters per respiration	457	1,250	1,250	986	1,028
Cubic centimeters per minute				10,850	10,300
Natural breathing in trunk-vertical position					
Respirations per minute	14	16	10	13	15
Cubic centimeters per respiration	413	625	1,000	679	558
Cubic centimeters per minute				8,830	8,370
Pole top artificial respiration					
Respirations per minute	10	14	10	11	10
Cubic centimeters per respiration	875	1,111	1,111	1,032	1,363
Cubic centimeters per minute				11,340	13,630
Unconscious					
Natural breathing in prone position					
Respirations per minute	17	18	19	18	
Cubic centimeters per respiration	172	384	237	264	
Cubic centimeters per minute				4,752	
Original Schafer artificial respiration*					
Respiration per minute	11	11	12	11	
Cubic centimeters per respiration	430	714	625	590	
Cubic centimeters per minute				6,490	
Modified Schafer artificial respiration**					
Respirations per minute	9.5	10	12	10	
Cubic centimeters per respiration	571	910	768	746	
Cubic centimeters per minute				7,460	
Natural breathing in trunk-vertical position					
Respirations per minute	21	17	19	19	
Cubic centimeters per respiration	170	367	280	272	
Cubic centimeters per minute				5,168	
Pole-top artificial respiration					
Respirations per minute	11	12	13	12	
Cubic centimeters per respiration	714	912	770	799	
Cubic centimeters per minute				9,588	

* Hands held in position between pressure strokes.

** Hands allowed to slip off at the end of each pressure stroke.

Table II

	Percentage Increase Over Control Period—Air Moved Per Minute		Percentage Increase Over Control Period—Air Moved Per Respiration		Percentage Difference in Air Moved Per Minute by Artificial Respiration While Patient Is Anesthetized Compared With Normal Breathing While Patient Is Conscious
	Conscious	Anesthetized	Conscious	Anesthetized	
Original Schafer artificial respiration	32 (33) *	37	43 (59) *	123	15 per cent decrease
Modified Schafer artificial respiration	41 (60) *	57	67 (89) *	183	3 per cent decrease
Pole-top artificial method	29 (63) *	88	52 (144)*	194	9 per cent increase

* Percentages for 15 conscious subjects, see reference 1.

percentage increases or decreases of the amount of air moved per respiration and per minute over the corresponding periods of natural conscious breathing of the three subjects. It is evident that the air moved per respiration under artificial respiration is equal to, or greater than, the natural breathing of the conscious subjects. The number of respirations per minute is less for the artificial respiration than for the natural breathing of the conscious subjects. In the cases of both Schaier methods there is a decrease in the air moved per minute in the unconscious state as compared with the normal breathing. The pole-top method records a slight increase in the volume of air moved per minute. Had the tempo of artificial respiration been increased to 13 times per minute, all three methods would have given equal or greater volume of air breathed per minute than for natural conscious breathing.

The bracketed figures in Table II are taken from the earlier paper.[1] They show a higher percentage increase in the volume of air moved than was found for the three subjects reported here. This suggests that a psychological factor may be involved in working with conscious subjects. The results obtained with the unconscious subjects are, however, not subject to this factor.

Conclusions

These studies give evidence of the relative efficiency of the three methods of artificial respiration studied, and so far as we know they represent the first effort to evaluate the worth of artificial respiration[3] in subjects under general anesthesia.

The data presented indicate that an equal or greater amount of air is moved in the unconscious (anesthetized) than in the conscious subject with each respiratory act. The modified Schafer method (hands allowed to slip off at the end of every stroke) is superior to the standard Schafer method, and the pole-top method is more efficacious in the trunk vertical position than the Schafer methods in the prone position.

It is apparent that all three methods of artificial respiration studied are more than adequate to supply the requisite pulmonary ventilation.

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Aircraft Signal Systems

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Synopsis: Because the selection of aircraft warning devices has not, in most signal installations, provided the pilot with dependable warnings of dangerous conditions, this paper proposes that aircraft signal devices should be designed and installed in compliance with the pilot's requirements as expressed in three design principles.

The publication describes the weaknesses of current signal devices; it recommends signal light indicators that are bright enough to be seen under direct sunlight; and it illustrates and describes an automatic dimming control that operates as a function of natural light, independent of pilot actions.

FORGETFULNESS on the part of the pilot to extend retractable-type landing gears initiated the requirements for positive-warning signal systems on airplanes. Malfunctioning of important equipment and co-ordination of crew activities brought about the requirements for informative signals in aircraft.

In addition to these requirements, pilots demanded warning signals for such items as gears "not locked," flaps "not down," fuel pressure "low," fuel level "low," oil pressure "low," and cabin "pressurization" "off." Informative signals were demanded for oxygen pressure "low," warning of icing conditions, bombing signals, paratroop "jump" signals, passenger call signals, crew call signals, and so forth.

To provide these signals for the pilot's use, it is necessary that the signal indicators should be designed correctly and that airplanes should be equipped with the necessary mechanical or electric pickups, consisting of easily serviceable actuating devices or limit switches, pressure switches, temperature switches, and control relays. These electric-signal pickup devices and controls have been available for some time as serviceable and reliable parts and are beyond the scope of this paper.

The signal indicator is the only controversial item in the airplane signal system, and manufacturers, in attempting to provide suitable signal indicators, have resorted to mechanical flags, vibrators, bells, horns, position indicators, indicator lights, telltale panels, and similar devices to serve as warning signals and as informative signals. The selection of these devices for the signal indications on airplanes has been made, in too many cases, by compromise decisions which have been influenced by restrictions rather than by principles. The result of such selection of indicators is that many signal systems on airplanes are not serving the purpose intended.

The purpose of this paper, therefore, is to outline the design principles that aircraft signal indicators should satisfy, to discuss existing signal indicative devices and to what extent they comply with these principles, and to suggest signal-system methods for improving the pilot's "workshop" so as to relieve him of unnecessary duties and thereby lessen pilot fatigue.

Design Principles

The following principles usually are common to the design of all warning signal indicators and to the design of most of the informative signal indicators in aircraft signal systems.

Signals Must Be Absolute

The first principle to be satisfied in providing signal indications is that the signal device should, by independent action, bring about decisive, positive, and effective action. Thus, aircraft-warning signal devices should, in themselves, provide indications which incite the pilot's reflexes in such a manner that he will change quickly and unquestionably to the obvious alternate course of action. Informative signal devices complying with this principle should show, in addition, directive indications. This directive-type indication is necessary to avoid creating any degree of confusion in the mind of the pilot or crew member, as the course of action may be perplexing for the moment.

Signals Distinct

The second basic rule to be followed in designing a signal indicator is to construct the indicative device so that it will emit signals which are distinct, abrupt, attractive, inescapable, and in definite contrast to everything in the proximity of the signal during any flight condition.

Signals Not a Hazard

The third principle to be observed in designing signal indications is to be sure that the signal does not constitute a hazard and thereby handicap the pilot in performing his operations. Violation of this principle is exemplified in installations where the brilliance of light signals is not modulated as a function of the natural light.

These principles are not new, and they are seldom ignored by the commercial control engineer. Most aircraft engineers would like to follow these laws but cannot because of the inertia of the aircraft industry against cost of the correct device in terms of weight, special design studies, and manufacturing or procurement complications. It is because of this cumbersome inertia and a desire for improvement of aircraft signal systems that the comparative description of signal devices is discussed in detail in the next section of this paper.

Existing Systems

Visual Mechanical Signals

Flags and mechanical indicators are the oldest type of warning and informative signal devices. They have been used in the airplane industry on small airplanes for such items as landing gear, flap, and tab position indicators. Examples of this type include push-rod and vane indicators on landing-gear mechanisms, spring- or cable-actuated scale and pointer combinations, solenoid-operated flags, and solenoid-operated targets that become visible by natural light or black light.

These devices have been selected by airplane manufacturers, because they are simple to design, install, and maintain, and because of the small number of parts that need to be replaced.

Fundamentally, all of these visual-type indicators depend on their warning by reflected light. The dependence on auxiliary light sources, and the fact that the signals are not abrupt or distinct enough to attract consistently the pilot's attention cause these signals to be considered undesirable warning signals.

In general, it may be stated that flags, mechanical indicators, and solenoid-actuated indicators obviously comply with the third principle, but do not satisfy completely the first and second principles discussed in the preceding section. These devices do not satisfy the first principle,

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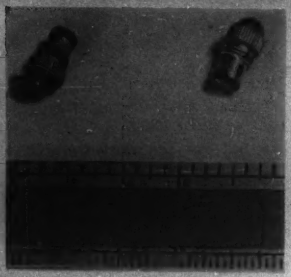

Figure 1. Lens-end signal lamps. General Electric Company T 1 1/4, 3 volts, 3 amperes, BM base

because they are not self-sufficient in themselves, for the reasons that they require auxiliary illumination, are not always positive, and, therefore, do not bring about immediate action. This type of signal does not comply with the second principle, because its indications are not abrupt enough, are not inescapable from the pilot's vision, and are not in sharp contrast to all other images meeting the eye.

Vibrators

Foot-pedal vibrator-type signals partly comply with all three design principles, but in most installations signals of this type do not fulfill the requirements of the first and second principles. Many pilots have expressed difficulty in interpreting the meaning of the signal, while others complained of the lack of contrast of the vibration signal with the normal vibration of the airplane.

Audible Signals

On practically all large airplanes designers have installed audible-type signals such as high-frequency vibrators, bells, and horns as warning and informative signal devices. Although these audible signals, when properly installed, comply with all three of the design principles, the characteristics of this type of signal limits the installation to one or two signals (the distance warning signals can be installed from the pilot's ear) and to the objections raised by air-line operators if warning or informative call signals can be heard by the passengers.

The advantages claimed for this type signal include:

1. The convenience of mounting in waste spaces.
2. The fact that no modulation of the signal volume is required during flight operations.
3. The fact that the need of replacements is rare.
4. Convenience of electric wiring for remote actuation of the audible indicator.

An example of audible warning or informative-signal indicator is the vibrator-type horn built to conform to Army-Navy specification *AN-S-8*.

Figure 3. Telltale device as installed in Curtiss-Wright AT-9 airplanes

This telltale is a visual warning device mounted on the instrument panel and contains 18 warning and informative signals as shown. Constant checking and rechecking of the instruments by the pilots has been eliminated, as this device is electrically connected to necessary instruments, controls, and component operating parts of the airplane, in such manner as to report immediately and constantly on their operation. These operations are shown by individual lighted signals on the telltale panel which are operated by limit switches, pressure switches, and so forth. The signals, as arranged, function as a "negative-warning" signal device, as a perfectly dark panel indicates correct operation of the items

Instrument-Type Signal Indications

Position indicators in some cases have been used to provide warning or danger signals as well as informative signals. Many aircraft manufacturers have installed indicators of this type for the purpose of combining warning or danger signals with informative position indications in a centralized location.

These combination position and warning-signal indicators are available with two types of warning signals. In one type the warning signals are manifest by mechanical flags which disappear when the landing-gear units are in the locked position. The other type indicator utilizes signal lamps as warning signals.

This combination instrument, known as *GE 8DJ4Y6*, when equipped with the signal lights, is an excellent centralized signal and position device in that it satisfies all three of the design principles, provided that the brilliance of the light matches the natural light. As will be discussed under light signals, the brilliancy of the signal lights should be controlled by an automatic modulating or automatic step-type control to maintain proper brilliancy of the signal lamp to satisfy night and day flight conditions.

Light Signals

Colored lights have been used very effectively as warning and informative signals on all types of airplanes. The installation of these lights as warning signals has been accomplished in the conventional industrial manner, that is, a colored lens shielding a clear electric lamp.

The greatest disadvantage of light signals in any signal system is the necessity for controlling the brilliancy of the

Figure 2. Photoelectronic dimming control

signal light as a function of the natural light. It is this disadvantage that causes the criticism of light signals. This criticism is, of course, warranted, as light signals that are too dim to be distinct in bright sunlight do not comply with the second design principle, whereas light signals that are too bright at night constitute a hazard to the pilot.

In view of this brightness factor, most airplane manufacturers have provided manually operated mechanical or electrical dimming devices to adjust the brilliance of the light signal to correspond to the natural light in the cockpit or control room. These manual devices, however, do not solve the light-intensity control problem for the reason that the pilot or crew member is not reminded to turn up the intensity of the signal light to match the sunlight conditions. Thus, it often happens during daylight operation that the warning light is energized, but no signal warning is noticed by the pilot for the reason that the light had been dimmed previously for night intensity. Even with semiautomatic schemes this condition still exists. For example, in signal-light installations where dimming is accomplished by the introduction of resistors by relay in the signal-light circuit by turning the navigation lights "on," the failure to increase the signal intensity is not prevented. Only the possibilities are reduced.

Bright-Beam Light and Photoelectronic Dimming Device

This year a signal-light system has been perfected that will satisfy all three design principles. Figure 1 shows the signal light itself, and Figure 2 illustrates the photoelectronic dimming device which controls the brilliance of any number of signal lights as a function of the natural light without any attention on the part of the pilot or crew member.

New Signal Lamp

The lamp shown in Figure 1, although similar to the General Electric Mazda 319 or 320 28-volt bombing signal lamp, is identified as a General Electric *T* 1¼, three-volt 0.30-ampere lens-end *BM*-type-base signal lamp.* This lamp was developed to produce a high-candle-power light beam which would serve as a distinct and inescapable light signal in direct sunlight. As of this writing, this lamp is the only unshielded signal lamp, suitable for aircraft uses, with which off and on can be distinguished readily under the direct rays of the sun.

This lamp was designed especially for low-voltage operation to insure long life (at least 250 hours) and to use a heavier and less-destructible filament. The lens in the lamp end is similar to the lens used in a "penlite"-type flash-light lamp. The lamps have been supplied in red, amber, blue, clear, and green.

Photoelectronic Dimming Device

The photoelectronic dimming-control device shown in Figure 2 is referred to as General Electric 7505-*L*-108. This automatic-control unit can be obtained to actuate automatically a relay, to open or close resistor circuits, which dims or brightens any number of signal lamps in accordance with the requirements for twilight or daylight.

As the photoelectronic tube is sensitive to any degree of light changes from one-foot candle and upward, the selection of photoelectronic units for any particular airplane can be obtained for dimming control in as many steps as desired.

The photoelectronic device shown in Figure 2 consists of a photoelectric tube, amplifier tube, sensitive relay, resistor, and mounting. The unit, as pictured, weighs less than a pound and operates from any 24-volt d-c supply.

Electric Cigarette-Lighter-Type Dimming Control

Another automatic device has been designed to control the dimming of signal lights, but the weight is about the same, and it does not offer complete control. This proposed device is a thermal time-delay switch which instantly dims the signal light for a five-minute period only, then snaps to the original bright position in much the same manner as an electric cigarette lighter. This device does not permit the signal-system installation to satisfy completely the third design principle, as it repeatedly constitutes a momentary hazard during night-flight operations.

Telltale

The telltale device shown in Figure 3, manufactured by the American Automatic Company *GH*-70,350, is a centralized signal indicator which incorporates all of the control-room signals into one compact panel. Installation, as made on many hundreds of airplanes, provides for 18 light-signal indications with the corresponding illuminated-directive nomenclature all arranged on a panel 3 by 3½ inches.

This device, in addition to showing warning and informative signals, includes directive signals to indicate to the pilot incorrect setting of important controls such as propeller, mixture, manifold pressure, carburetor heat, and trim tabs. Actuation of these directive signals in the telltale panel is accomplished by automatic switching that is a combined function of the control setting and the flight regime.

Considered as a whole, this device complies with all three signal-indication design principles, except those conditions under which the second principle is violated. Like the manual-control shutter-dimmed signal lamps previously mentioned, the telltale unit is susceptible to daytime operating conditions where the dimming shield could be partially closed for night operations, and the pilot would overlook the telltale signals. As was discussed under "Light Signals," an automatic dimming device would correct this difficulty, and the telltale signal indicator would then satisfy all three design principles.

Concluding Recommendations

From the discussion given in this paper, it is recommended that all warning and informative signals should be light signals which are bright enough to be seen under direct sunlight. As part of this recommendation, it is suggested that the light intensity of the warning and informative signals should be controlled automatically as a function of day or night operation. For special requirements the light intensity should be modulated automatically or adjusted in steps to correspond with the natural light. Referring to the three design principles mentioned at the beginning of this paper, it is believed that a signal indicator complying with these suggestions will provide light signals which are absolute, always can be detected, and will not constitute a hazard to the pilot.

It is further suggested that to reduce pilot fatigue and to eliminate unnecessary searching of instrument indications more signals should be added to the airplane signal system. By the same reasoning it is recommended that these additional signals should be grouped into a centralized location in a manner similar to that utilized by the telltale panel shown in Figure 3.

* *BM*-type base refers to the special lamp base designed to match the Bardwell-McAlister lamp socket.

Cultural Training of the Engineer

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IT is generally recognized that a professional man must have a certain amount of cultural training, in addition to the technical, so as to be better balanced, more useful to the society, and more successful; and engineering curricula generally make provision for it. However, it appears questionable whether the cultural program is as well suited to its objectives as the technical programs are to theirs. As a parent, the author had occasion to look into this matter during the past several years and was led to the conclusion that the quality of the conception and execution of the cultural training of the engineer is definitely inferior to that of his technical training.

Although the author would be pleased if this paper should stimulate a general discussion and careful review of the situation by competent authorities, leading to its amelioration, yet his immediate purpose is more modest—to share some of his thoughts on this matter with the parents of prospective technical students.*

A Basis for Planning

Considering the great variety of cultural subjects and the wide divergence of tastes, it may be a question whether a generally acceptable cultural program can be planned. Think of the cultural value and fascination of the fine arts—music, painting, sculpture, architecture, dramatics, dancing, and so forth. Of the classics—poetry, fiction, drama, essay, mythology, and so forth. Of philosophy —logic, metaphysics, and so forth. Of the social subjects—sociology, anthropology, even archeology, politics, economics, and so forth. And history—political, social, revolutionary, and so forth. And—but why enumerate more?

What shall we recommend to our sons specializing in science or technology? Is there a basis for choice other than individual taste?

I think there is such a basis, and it is to be found in certain common and urgent needs of the average student. The shortage of available time for this purpose makes it imperative to pass by most of the fascinating subjects mentioned, to assure that certain "must" subjects are properly taken care of first.

Student's Needs

I think we can get general agreement on at least the following three cultural needs of the average student as fundamental:

1. Knowledge of and skill in studying efficiently.
2. Knowledge of and skill in dealing with himself and others successfully.
3. Ability to express himself well in speech and writing.

Let us examine each item in its turn.

1. How to study is perhaps the most pressing problem of the freshman. Little or no instruction is given in this matter by the faculty; in its place, frequent quizzes are given to "put the screws on" the freshman. He must discover for himself how to study or be eliminated. This should have been learned at the high school, but it was not. The fellow was then still a "darling boy," and we regretted that he had to do homework at all, instead of being out in the fresh air or in bed, or having fun with other young people—boys and girls. Unprepared for serious study, the freshmen fret and swear, smoke and scribble and spit, and, finally, about half of them evolve some temporary *modus vivendi* whereby they survive for four years to receive their diplomas. After that, books and studies may go overboard. Four years of those things were too much already!

2. How to deal with himself and others is another great problem of the student, but he is not generally aware of it, and no particular attention is paid to it by the faculty.

Years ago, at a gathering of young engineers, a big engineering executive was asked for the key to success. "Boys," he said, "Pay close attention to your mathematics;" but, later, when the same question was put to him again, now by a friend of his and in the privacy of his home library, the answer was: "George, the key to success in engineering is 40 per cent technology, 60 per cent diplomacy."

Whether it is called diplomacy, or social psychology, or simply human relations, a certain amount of proficiency in it is essential in the successful practice of engineering. More of it is required, of course, in managerial positions than in the ranks, but that the latter group frequently do not possess even the modicum that they need is indicated by the published experience of one large organization to the effect that in a period of depression the selection of technical men for layoff was more often for lack of co-operativeness than for lack of technical ability.[1]

It is probably safe to predict that the student who is brilliant in technology but just passable in human relations will in time work for the one who was just passable in technology but brilliant in human relations.

3. As for self-expression, technical schools pay only a limited attention to speech but are generally interested in writing, and in this the freshman is traditionally deficient. This deficiency is supposed to be due to lack of knowledge of the English language, and so the freshman is required to take English. But the principles of good writing are the same in any language, so good writing cannot be a matter of knowing the English language. Good writing can be done (frequently is done by the masters) in various dialects and slang; it can be done in basic English, even in pigeon English! Think of the gems in negro dialect! Knowledge of good English usage is of course highly desirable, but too much is expected of it when it is assumed that knowledge of English is the main thing in writing well.

Just because writing is important, speaking should not be treated casually. Speaking ability is a greater asset for an executive than writing ability. After all, should the necessity arise, it is possible to hire someone to write for you but not to speak for you. Furthermore, a good speaker can always produce a good manuscript by dictating as if he were giving a talk; but let a person talk as if he were writing a technical paper—what a disappointment that would be! Dr. Heiser has told us the secret of how he wrote his best seller, "An American Doctor's Odyssey." He realized that if he sat down to write his experiences, the product would probably be "a dry Rockefeller Foundation report." So he changed his plan. He knew that through years of practice he could talk fairly interestingly, so he hired an alert newspaperman to interview him, and a stenographer to record the interview. A best seller was

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* The views expressed here are those of the author himself and do not necessarily represent those of the company with which he is associated.

thus produced in a short time and without the usual drudgery of book writing.

I believe that for the average professional man the ability to speak before a group clearly, convincingly, and gracefully is a greater asset than ability to write well.

Urgency of the Problem

These three needs of the student cannot be postponed. He must acquire in his freshman year not only an efficient study technique, but also a variety of other habits essential to a successful personality. The college term, particularly the freshman year, is the terminal period of transition from the plastic to the relatively nonplastic phase of life and may be looked upon as the student's last opportunity to shape his personality into a desirable pattern. Soon he will be "set"; he will become a mere "walking bundle of habits," to quote William James, the psychologist. A complex network of intellectual, emotional, and motor habits will then constitute his entire personality and will determine even the details of his professional style and judgment. If this complex of habits is developed haphazardly and unawares, what probability would there be of anything but a mediocre personality developing, unless an exceptional heredity or a great inspiration or an exceptional set of circumstances should exist?

Credit units in classics and metaphysical speculation may be helpful but would not assure the kind of culture that a parent is likely to contemplate for his son. Furthermore, culture has not been acquired until it has become second nature through habit. The college years therefore should be utilized eagerly as the student's last opportunity to form these habits by practice with reasonable ease and under competent guidance.

Meeting the Needs

The basic cultural course generally required at the present time is English, but it is the opinion of this writer that if the foregoing needs of the student are true, they can be met best by practical psychology. It is not advocated that English be dropped but rather that it be approached as a problem in psychology rather than one in language.

Of course, a course in psychology is not necessarily cultural. It will not be so unless it is competently planned and conducted for this end. Let us note some of the features of such a course.

(*a*). The most important topic in practical psychology for our purpose is that of habit. The classic Chapter III on habit in James's two-volume psychology (or its equivalent) should be used as the text for half a dozen lessons, coupled with a judiciously chosen set of exercises in habit formation. The student should realize that there is infinitely more to habit than nail-biting or smoking; that it is the one great principle of personal efficiency, because it is the principle of mechanization—automatization—of human behavior; and that not the breaking of so-called bad habits but the building up of his idealized social and professional personality through conscious, systematic, and habitual formation of habits is the major interest of habit psychology. As the student is made habit-conscious and as he develops a few judiciously chosen pleasant and profitable habits as laboratory exercises and gets the "feel" of it, he will be incidentally forming the most important habit—the master habit—namely, the habit of soundly planning and promptly mechanizing as much of his routine life as possible so that his mind may be relieved of routine drudgery and be set free to engage itself in more pleasant tasks and greater achievements. With proper work, study, play, and social habits formed (or at least well started) in the freshman year, the student is prepared for the most efficient utilization of his time and abilities for the development of his professional skills and personality during the following three years.

Habit psychology is a basic principle of any training, for training is primarily the conversion of knowledge into habit patterns by practice. If one thinks that the development of skill, rather than that of habit patterns, is the primary feature of training, he may do well to consult a good reference on habit psychology, in which he will discover that habit formation is the foundation of development of skills; for, after all, the major instrumentality in the development of skills is practice, and practice is inseparable from habit formation.

Many psychologists, engrossed in their specialties, do not seem to be actively aware of these things. The eminent psychologist, Dr. Link, has confessed as much—that he was not alive to these things until he observed the needs of his adolescent children.[3,4]

(*b*). The next most important topic in practical psychology is human motivation. Properly taught, this should enable the student to see quickly the other fellow's point of view which generally amounts to his motivation. Much of our nontechnical reasoning, especially in arguments, is nothing but rationalization, defense, and wishful thinking; in other words, biased or emotional thinking. That is why arguers never get anywhere with proofs. That is why an appropriate incentive convinces people so much better than logical evidence; and, as Hitler has demonstrated it, if the incentive is there, people will easily believe the biggest lies. "The will to believe . . ."

(*c*). The thought process and principles of clear thinking are naturally another important topic in psychology to be made clear to the freshman. Advertising psychology, political publicity, propaganda analysis, and scientific thinking, may be treated here in condensed form with great benefit and interest to the student.

(*d*). Then the eyes of the student must be opened to the power of attention and its significance towards his academic success. He should be enabled to see that the marvels of hypnotism are merely the product of an undistracted and concentrated attention; and that, if he wishes to be able to match the apparently superior power, intelligence, and memory of a hypnotized person, without the hocus-pocus of hypnotism, he can do so by cultivating his power of concentration. Would he then have any difficulty in studying at college or concentrating on creative work later?

(*e*). Practical psychology naturally forms the foundation of successful public speaking also. Many teachers of public speaking preoccupy the class with voice, posture, and other details to the exclusion of a psychological analysis of why a given speech is good or bad. "Not what to say but how to say it" is the watchword of some of them, the "how" being interpreted rather narrowly. But "what to say" is incomparably more important than "how to say it." If the presentations of papers at the AIEE meetings are frequently unsatisfactory, the basic reason, I think, is a lack of understanding of the psychology of the audience. The speaker probably is talking to a few specialists like himself sitting near the front to hear him well. That is why the rest don't hear him well; and when they do hear him, they do not understand what he is saying. I expect that if the psychology of the speaker is corrected, his voice and other important faults will automatically correct themselves.

Out of the mass of thoughts that are always available within the scope of the subject and the knowledge of the speaker, the selection of those which are best adapted to the background of the audience, the arrangement of those thoughts

in a logical sequence, the phrasing of them in graceful fashion, and their presentation in an audible pleasing manner, is the common sense of good speaking as the audience itself would define it; and the audience, as the customer, is right.

It is well enough to have public speaking taught to technical students by professional public-speaking teachers, but in some cases it may be necessary to supplement such instruction by having one or more technical men gifted in public speaking and able to make psychological analysis of a given speech sit in at the classes as audience and critics.

(f). The basis of good technical writing also has to be practical—common sense—psychology. This requires the selection of essential information, its arrangement in logical order, and its expression in a manner that will be clear and interesting to the intended readers. How little the study of the English language has to do with this! The knowledge of English—vocabulary and grammar—of the average freshman is fully adequate for his needs. The training he needs is in organizing his thoughts and expressing them in the words he knows. Of course, the study of the masters of English style is helpful and to be recommended within the very limited time available for that particular purpose, but we must not also forget the desirability of developing the student's own individual style. Too much emphasis on masters can destroy the student's individual style.

The merits of the student's English composition or technical report should be analyzed and appraised not from the standpoint of language but from the standpoint of the psychological principles of holding the reader's attention, imparting information to him and influencing his reaction in a desired direction. A course in English composition in which the instructor does no more than editorial corrections, I should consider a waste of student's time.

(g). The success of a course in English literature as a cultural medium depends on how it is selected and how approached. The point of view of a professional "litterateur" can have little cultural value for the engineer. For instance, I pick up a book by an eminent literary critic, entitled something like "The Stories I Have Enjoyed." I read a selection and am disgusted—no big idea, no real human interest in it. Then I find out that the critic selected it because the technique of that kind of a story is considered very difficult, and the author of this story "got away with it." Over and over again I have observed literary critics (and musical critics) discuss at length considerations that can be of very little interest to those with only a general cultural interest in the matter.

What makes great literature great—the kind that lives through the centuries—is not its linguistic skill, but the profound insight into human nature that it exhibits; for instance, Shakespeare. But even the cultural value of a course in Shakespeare can be spoiled for the engineer by approaching it from the standpoint of literary technique.

In order to serve best the interests of the engineer, the teacher of literature must bear in mind constantly that what is needed is primarily a literature-appreciation course, carrying with it the following corollaries:

1. The teacher will have to work harder than the students. Especially in the composition work, he should be able and willing to rewrite the student's material and explain to him why one was bad and the other one is good.

2. Selections for reading must be chosen carefully and abridged to the limit to save the student's time. It will be better to err on the side of making it a "snap" course, rather than a difficult course which will antagonize the student and make him hate literature ever after. I should consider it a highly successful course if in literature the teacher accomplished no more than infusing the student with such an appreciation of good literature that the student will continue reading it in later years.

3. Engineering students should not be combined with those majoring in literature and made to follow the latter's volume of work and point of view.

Broader Obligations

The engineer is frequently criticized for not playing a leading part in the social, civic, and political problems of his community. To remedy it may require more than one measure, but it appears to this author that the first step in effective preparation for such leadership is for the engineer to understand the psychology of himself and his fellowmen. That done, a course in sociology, or government, or economics, and so forth, may be added if time permits. In any case, if the graduate is well grounded in the general principles of human behavior and relationships and has had some systematic practice in college, he can obtain later, by private study, any additional knowledge needed for the civic activity into which he may wish to enter effectively.

Life has many surprises, and we may at any time be thrown into unexpected problem-situations. In such cases, we may count on the engineer to solve the technical problems involved, even though they may be far outside of his specialty, and we may fear his failing on account of mismanagement of the human problems involved, unless he has had special training or was born with an instinct for the human equation. War is such a situation.

At the AIEE Northeastern District meeting in Pittsfield (April 1943), Colonel Beukema told us that the reports received from the officers in the field indicate that the soldiers with cultural training make better leaders, and therefore the Army specialized training program is making some provision for such training.[4] I understand that the Navy program is even more generous in this respect. While I do not know whether the Army or the Navy has made any appraisal of the value of different cultural courses for its purposes, the type of basic cultural training here advocated would seem to be superior to classics, philosophy, and so forth, for the fighting man.

Problem of Time and Place

The minimum cultural training advocated here can certainly be had in the time now allotted for the humanities. It appears to this writer, however, that those who are particular about the nature and quality of such training are likely to ask for more of it and for some additional subjects, thereby prolonging the curriculum by another half year or full year. In normal times and the long run, I think the student is likely to be well repaid for the extra time. A five-year curriculum for the engineer is not unreasonable compared with the seven years many chemists are putting in now (to secure a degree of doctor of philosophy), the eight years that physicians generally put in, and the five to seven years that the requirements of some of the graduate schools of engineering entail.

As to the place, as things stand now, some students may find it necessary to consider the advisability of dividing their time between two institutions, one for the cultural courses, the other for engineering, especially if an extra year is to be devoted to the purpose. This naturally raises questions of loyalty and the difficulty of achieving advanced positions in the social and extracurricular activities in either institution, which in their turn work contrary to the major goal. I think certain arrangements have less objectionable features than others. The most proper solution of the problem is that the cultural curricula of the engineering schools be made as efficient as their engineering curricula.

Design of Starting Windings for Split-Phase Motors

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ALTHOUGH split-phase induction motors are built annually in millions of units, involving thousands of designs, little can be found in the technical literature concerning the design processes.

The usual procedure is to fix the main stator winding and the squirrel-cage rotor from specifications covering the maximum torque and the general running performance. The procedure for the direct determination of the stator winding to yield a required maximum torque is already available.[1]

The problem presented in design, after the determination of the main winding, involves the selection of starting winding turns and wire size. It is generally necessary that the completed design meet specified values of starting torque without exceeding limits of starting amperes. Such limits may be fixed by various standards or by customer's requirements.

It is very likely that some element of trial and error exists in the methods most commonly employed for starting winding design. An obvious approach is to assume a starting winding, calculate the circuit constants, and from these obtain the calculated values of starting torque and current. If the values are not suitable, a readjustment of the winding is necessary. Such readjustment may result in satisfactory values for one critical factor but not another. Continued trial and error may result in a final, satisfactory design. In such a process, the designer has three variables which can be controlled, namely winding distribution, number of turns, and wire size.

On the completion of a satisfactory design, the designer may still be troubled by the suspicion that, had some other combination of factors been used, still better results might have followed.

It is the purpose of this paper to present a method of design which will yield directly the starting winding turns required:

(*a*). For a given starting torque.

(*b*). For a given starting current.

If either is used as a criterion for design, it is always necessary to check the other characteristic. This can be done by referring to a few simple curve sheets, requiring no complicated calculation. A number of other relationships are developed, enabling the designer to apply proportion more intelligently in modifying existing designs.

The writers have investigated the possibilities of making up a series of curve sheets covering all reasonable values of split-phase winding parameters to enable torque and current to be read more or less directly, with little calculation. Because of the number of quantities involved, such an approach seemed impractical.

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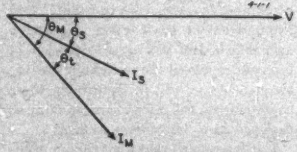

Figure 1. Vector relationships at instant of starting

Method of Approach

The items determining starting performance are chiefly:

(*a*). Rotor resistance and leakage reactance; main winding resistance, and leakage reactance.

(*b*). Starting winding resistance and leakage reactance.

The rotor quantities, referred to the stator main winding, differ in value from those same quantities, when referred to the starting winding, by the square of the transformation ratio. The starting winding reactance differs from the main by the same ratio squared. Hence, all starting winding parameters can be obtained in terms of the main winding, excepting the starting winding resistance. The method employed in this paper is to obtain the starting winding resistance in main winding terms. When that is done, *all* starting winding parameters can be expressed as a function of the main winding, and it in turn has been fixed by previous considerations. The resulting calculations are greatly simplified.

Expressions for Starting Torque

Several formulas are available for starting torque. A simple form is:

$$T = \frac{225.4}{\text{Syn. rpm}} I_M I_S \frac{r_2}{a} \sin \theta_t \text{ (ounce-feet)} \quad (1)$$

All terms are defined in the list of symbols.

This formula is conveniently expanded thus:

$$I_M = \frac{V}{Z_M} \quad (2)$$

$$I_S = \frac{V}{Z_S} \quad (3)$$

$$\theta_t = \theta_M - \theta_S \quad (4)$$

By the trigonometric expression for the difference of two angles:

$$\sin \theta_t = \frac{X_M R_S - R_M X_S}{Z_M Z_S} \quad (5)$$

Since the acceptance of this paper by the Institute, the author's attention has been called to two articles in *The Journal of Engineering Education*, one describing the Army Specialized Training Program,[5] the other that of the Navy.[6] The first contains a splendid outline of the objectives in the English course. The Navy program is particularly interesting in that it prescribes for the electrical engineers a course in English in the first year and in psychology in the second and fourth years. The details of these courses are not outlined.

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1. CHARACTERISTICS OF A GROUP OF ENGINEERS, Thomas Spooner. AIEE TRANSACTIONS, volume 53, 1934, pages 1571–6; discussion, volume 54, 1935, pages 757–60.

2. THE RETURN TO RELIGION, Henry C. Link. Chapter VI, "Children Are Made," pages 93–7.

3. PERSONALITY CAN BE ACQUIRED, Henry C. Link. *Readers Digest*, December 1936.

4. TRAINING TECHNICAL LEADERS FOR WAR—THE ARMY PROGRAM, Herman Beukema. ELECTRICAL ENGINEERING, volume 62, March 1943, pages 89–93.

5. *The Journal of Engineering Education*, April 1943, page 558.

6. *The Journal of Engineering Education*, April 1943, page 630.

Using these items, we then have:

$$T = \frac{225.4V^2}{\text{Syn. rpm}} \cdot \frac{r_s}{s} \cdot \frac{X_M R_s - R_M X_s}{Z_M^2 Z_s^2} \quad \text{(ounce-feet)} \quad (6)$$

As shown here, the equation assumes that the equivalent circuits of the main and start windings are each simple series circuits, containing no magnetizing current component. If a magnetizing branch is assumed to be connected across the circuit midway between the stator and rotor constants, then the so-called theoretically exact circuit results, with greater accuracy of calculation. To accomplish this greater accuracy, the flux factor K_f will be used as shown. We then have

$$R_M = r_{1M} + K_f r_2 = r_{1M} + r_0 \quad (7)$$

$$X_M = x_{1M} + \sqrt{K_f} x_2 \quad (8)$$

It will be assumed, therefore, throughout this paper that the leakage reactance for the main winding of the stator and the rotor is expressed as shown in equation 8, and that r_0 is used in place of r_2. This compensates for the effect of the magnetizing current component. We can now write the following equation for the terms used:

Total impedance in main winding items:

$$Z_M = \sqrt{R_M^2 + X_M^2} \quad (9)$$

Total resistance in starting winding terms:

$$R_s = r_{1s} + (r_0/a^2) \quad (10)$$

Total leakage reactance in starting winding terms:

$$X_s = (X_M/a^2) \quad (11)$$

Total impedance in starting winding terms:

$$Z_s = \sqrt{R_s^2 + X_s^2} \quad (12)$$

The ratio of transformation:

$$a = \frac{C_M K_{WM}}{C_S K_{WS}} = \sqrt{\frac{X_M}{X_s}} \quad (13)$$

Some comment should be made concerning this ratio. Theoretically, the correct value would involve the turn ratio. It is customary to correct the leakage reactances as calculated by applying a constant which is a function of the winding factor, K_W. One such correction curve in common use[2] is nearly parabolic in shape. On that portion of the curve where it follows such a law, the ratio of transformation obtained from the effective turns is exactly the same as the ratio obtained from the leakage reactances. For high values of K_W a slight discrepancy results. This will be neglected here and the relationships of equation 13 assumed as uniformly accurate.

If equation 6, with the expanded constants of equations 7 to 12 substituted, is differentiated with respect to starting winding resistance (treating a as a constant), the condition required for maximum starting torque can be obtained. This condition is:

$$r_{1s} = \frac{1}{a^2}(r_{1M} + Z_M) \quad (14)$$

Since a may have *any* value, the conditions in equation 14 can be satisfied by an infinite number of starting windings, and, so long as a^2 times r_{1S} equals $(r_{1M} + Z_M)$, each will yield a different maximum starting torque. It is important to note that there is no single value of maximum starting torque. The significance of the solution for maximum rests in this fact: with the main winding fixed by running conditions $(r_{1M} + Z_M)$ is a constant. Any combination of turns, ratio, and resistance which does not satisfy equation 14 does not represent the maximum starting torque. As an aid in identifying these conditions we will refer to any winding so designed as a "maximum winding."

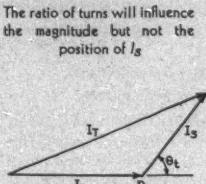

Figure 2. The angle θ_t is fixed for all maximum windings which can be supplied

If it is assumed that a maximum winding is always to be supplied in the derivations which follow, we can write the following equations:

$$R_S = r_{1s} + \frac{r_0}{a^2} = \frac{r_{1M} + Z_M}{a^2} + \frac{r_0}{a^2} \quad (15)$$

$$R_S = \frac{1}{a^2}(R_M + Z_M) \quad (16)$$

$$Z_S = \frac{1}{a^2}\sqrt{2Z_M(Z_M + R_M)} \quad (17)$$

These values can now be substituted in the starting torque equation, yielding the following:

$$T = \frac{112.7 r_0 a}{\text{Syn. rpm}} \cdot \frac{V^2}{Z_M^2} \cdot \frac{X_M}{Z_M + R_M} \quad \text{(ounce-feet)} \quad (18)$$

This is the maximum starting torque for a given ratio a.

The preceding formulas show two significant facts.

As the starting winding is changed, keeping the product $r_{1S}a^2$ at the correct constant value, the starting torque will increase directly as the ratio of transformation a. The current in the starting winding will vary directly as a^2. This follows from equation 17.

Slot Space Required

With the various sizes of wire and number of turns available for maximum windings, the question naturally arises as to the relative slot area required for the various combinations. This will be investigated.

In general:

$$r_{1S} = 0.87 \frac{l_c C_S}{A} \quad (19)$$

$$a = \frac{C_M K_{WM}}{C_S K_{WS}} \text{ (from equation 13)}$$

Therefore

$$r_{1S}a^2 = \frac{0.87 l_c}{A} \cdot \frac{K_{WM}^2 C_M^2}{C_S K_{WS}^2} = (r_{1M} + Z_M) \quad (20)$$

or

$$AC_S = \left(\frac{0.87 K_{WM}^2 C_M^2}{(r_{1M} + Z_M)}\right)\left[\frac{l_c}{K_{WS}^2}\right] \quad (21)$$

The terms in parentheses all apply to the main winding and are not subject to change. The terms in brackets are fixed by the starting winding distribution but are independent of the number of starting winding turns. Hence, the right-hand member of this equation is a constant for a given starting winding distribution. The product AC_S represents the circular mils per conductor times the number of starting winding conductors or the total useful slot area devoted to starting winding. Hence, regardless of the various combinations of turns and wire sizes, if they result in maximum windings, the total slot areas required for the starting windings are identical.

Or, if the total slot area for starting windings is fixed by heating considerations or otherwise, the maximum winding becomes fixed as indicated previously. This does not preclude the possibility of obtaining a winding which is apparently better than the maximum winding if the slot area for the starting winding is allowed to vary. This point is illustrated in the discussion of the table of results which is presented later.

This conclusion is based on a fixed distribution for the starting winding. In

case the total area given by equation 21 is too large, can any other distribution result in a satisfactory maximum winding which requires less slot area? To investigate this, it is first necessary to derive the expression for the slot area required for the largest starting winding coil.

Circular mils of copper for the fullest starting winding coil

$$= [0.87 K_{WM}{}^2 C_M{}^2/(r_{1M}+Z_M)]\,[l_c/K_{WS}{}^2 S'] \quad (22)$$

where S' is the equivalent number of full slots for the starting winding. (Thus, if a four-pole 36-slot motor had a winding distribution for the starting winding of two 100 per cent coils and two 50 per cent coils under each pole, S' would be 24.) The terms in brackets are all functions of the distribution. If it is assumed that Appleman's[3] distributions for sinusoidal space waves are used, the bracketed quantity varies from 1.20 to 0.70 for the range investigated. The smaller quantity resulted from a wider distribution. Hence, we can conclude that, as more coils per pole are used, the maximum winding required less slot area.

Vector Relationships

The starting torque varies directly as the sine of the time angle between the starting and main winding currents. Refer to Figure 1. From equations 16 and 17, it is obvious that

$$\text{Sin}\,\theta_t = \frac{X_M}{\sqrt{2Z_M(Z_M+R_M)}} \quad (23)$$

$$\text{Cos}\,\theta_t = \frac{Z_M+R_M}{\sqrt{2Z_M(Z_M+R_M)}} \quad (24)$$

Since these terms are all functions of the main winding, it follows that for all maximum windings the angle θ_t is fixed. Then as r_{1S} and a^2 are varied (keeping the same product), the point p moves from $p_1=0$ to $p_2=\infty$ as in Figure 2.

Starting Currents

The total starting current is:

$$I_T = \sqrt{(I_S \sin\theta_t)^2+(I_S\cos\theta_t+I_M)^2} \quad (25)$$

or in terms of winding constants for maximum windings:

$$I_T = V\sqrt{\frac{a^4}{2Z_M(Z_M+R_M)}+\frac{1+a^2}{Z_M{}^2}} \quad (26)$$

The current in the starting winding is:

$$I_S = \sqrt{I_T{}^2 - I_M{}^2\sin^2\theta_t} - I_M\cos\theta_t \quad (27)$$

Since each maximum winding will require a different total starting current and this current is limited usually by design specifications, it is useful to determine the ratio of transformation which will yield a required number of starting amperes. This can be obtained by solving equation 26 for a^2. Thus:

$$a^2 = \sqrt{2Z_M(Z_M+R_M)}\times \frac{\sqrt{I_T{}^2 - I_M{}^2\sin^2\theta_t} - I_M\cos\theta_t}{V} \quad (28)$$

A simpler method of determining a for a given starting torque is shown later.

Starting Torque Per Ampere

Faced with a limit on starting current and a starting torque value which must often be kept high, the starting torque per ampere of starting current is an important figure. For all of the maximum windings which the designer can apply to a given job, the question naturally arises as to whether any proposed winding is producing as much starting torque as is possible for the limiting current. For that reason an investigation of the conditions for maximum starting torque per ampere is of interest.

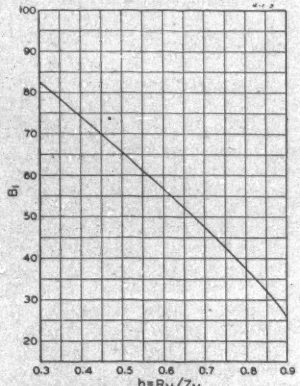

Figure 3. Constant for calculating starting torque

Equation 18 expresses the torque obtained from a maximum winding. For simplicity, the square of the total starting current will be used in setting up the ratio. Then from equations 18 and 26

$$\frac{\text{St.T}}{I_T{}^2} = \frac{112.7 r_{1S}}{\text{Syn. rpm}}\cdot\frac{2X_M}{2(Z_M+R_M)(1+a^2)+Z_M a^4} \quad (29)$$

When this is differentiated with respect to a and the result equated to zero, the maximum value for equation 29 is obtained. For this condition:

$$a^2 = \frac{(Z_M+R_M)+\sqrt{(Z_M+R_M)^2+6Z_M(Z_M+R_M)}}{3Z_M} \quad (30)$$

Working Curves

The formulas given up to this point can be simplified and the results plotted into useful curves by employing the ratio of constants R_M/Z_M. Let

$$b = R_M/Z_M$$

Then equation 18 becomes

$$T = I_M{}^2 \frac{ar_0}{\text{Syn. rpm}}\left[\frac{112.7\sqrt{1-b^2}}{1+b}\right]$$

The quantity in brackets is plotted for a range of b values and is designated B_1. This is of value in determining the starting torque after a has been selected. See Figure 3.

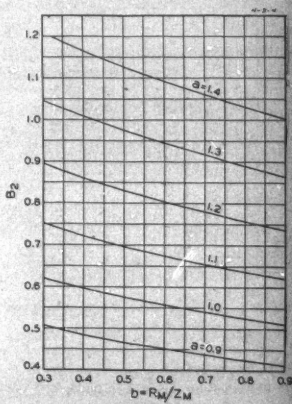

Figure 4. Relation between current in starting and current in main windings

The ratio of currents in the two windings:

$$I_S/I_M = Z_M a^2/\sqrt{2Z_M(Z_M+R_M)}$$

If the b ratio is used, this can be expressed:

$$I_S/I_M = \left[\frac{a^2}{1.41\sqrt{b+1}}\right]$$

The quantity in brackets will be designated B_2 and is plotted for a range of values of b in Figure 4. This is useful for determining the starting winding current after a has been selected.

To determine the ratio of transforma-

Using these items, we then have:

$$T = \frac{225.4V^2}{\text{Syn. rpm}} \cdot \frac{r_2}{a^2} \cdot \frac{X_M R_s - R_M X_s}{Z_M^2 Z_s^2} \quad \text{(ounce-feet)} \quad (6)$$

As shown here, the equation assumes that the equivalent circuits of the main and start windings are each simple series circuits, containing no magnetizing current component. If a magnetizing branch is assumed to be connected across the circuit midway between the stator and rotor constants, then the so-called theoretically exact circuit results, with greater accuracy of calculation. To accomplish this greater accuracy, the flux factor K_r will be used as shown. We then have

$$R_M = r_{1M} + K_r r_2 = r_{1M} + r_0 \quad (7)$$

$$X_M = x_{1M} + \sqrt{K_r} x_2 \quad (8)$$

It will be assumed, therefore, throughout this paper that the leakage reactance for the main winding of the stator and the rotor is expressed as shown in equation 8, and that r_0 is used in place of r_2. This compensates for the effect of the magnetizing current component. We can now write the following equation for the terms used:

Total impedance in main winding items:

$$Z_M = \sqrt{R_M^2 + X_M^2} \quad (9)$$

Total resistance in starting winding terms:

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$$Z_s = \sqrt{R_s^2 + X_s^2} \quad (12)$$

The ratio of transformation:

$$a = \frac{C_M K_{WM}}{C_S K_{WS}} = \sqrt{\frac{X_M}{X_s}} \quad (13)$$

Some comment should be made concerning this ratio. Theoretically, the correct value would involve the turn ratio. It is customary to correct the leakage reactances as calculated by applying a constant which is a function of the winding factor, K_W. One such correction curve in common use[3] is nearly parabolic in shape. On that portion of the curve where it follows such a law, the ratio of transformation obtained from the effective turns is exactly the same as the ratio obtained from the leakage reactances. For high values of K_W a slight discrepancy results. This will be neglected here and the relationships of equation 13 assumed as uniformly accurate.

If equation 6, with the expanded constants of equations 7 to 12 substituted, is differentiated with respect to starting winding resistance (treating a as a constant), the condition required for maximum starting torque can be obtained. This condition is:

$$r_{1s} = \frac{1}{a^2}(r_{1M} + Z_M) \quad (14)$$

Since a may have any value, the conditions in equation 14 can be satisfied by an infinite number of starting windings, and, so long as a^2 times r_{1S} equals $(r_{1M} + Z_M)$, each will yield a different maximum starting torque. It is important to note that there is no single value of maximum starting torque. The significance of the solution for maximum rests in this fact: with the main winding fixed by running conditions $(r_{1M} + Z_M)$ is a constant. Any combination of turns, ratio, and resistance which does not satisfy equation 14 does not represent the maximum starting torque. As an aid in identifying these conditions we will refer to any winding so designed as a "maximum winding."

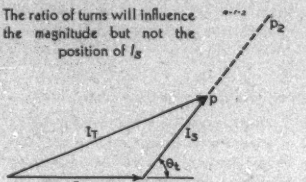

Figure 2. The angle θ_t is fixed for all maximum windings which can be supplied

If it is assumed that a maximum winding is always to be supplied in the derivations which follow, we can write the following equations:

$$R_S = r_{1s} + \frac{r_0}{a^2} = \frac{r_{1M} + Z_M}{a^2} + \frac{r_0}{a^2} \quad (15)$$

$$R_S = \frac{1}{a^2}(R_M + Z_M) \quad (16)$$

$$Z_S = \frac{1}{a^2}\sqrt{2Z_M(Z_M + R_M)} \quad (17)$$

These values can now be substituted in the starting torque equation, yielding the following:

$$T = \frac{112.7r_0}{\text{Syn. rpm}} \cdot \frac{V^2}{Z_M^2} \cdot \frac{X_M}{Z_M + R_M} \quad \text{(ounce-feet)} \quad (18)$$

This is the maximum starting torque for a given ratio a.

The preceding formulas show two significant facts.

As the starting winding is changed, keeping the product $r_{1S}a^2$ at the correct constant value, the starting torque will increase directly as the ratio of transformation a. The current in the starting winding will vary directly as a^2. This follows from equation 17.

Slot Space Required

With the various sizes of wire and number of turns available for maximum windings, the question naturally arises as to the relative slot area required for the various combinations. This will be investigated.

In general:

$$r_{1S} = 0.87\frac{l_c C_S}{A} \quad (19)$$

$$a = \frac{C_M K_{WM}}{C_S K_{WS}} \text{ (from equation 13)}$$

Therefore

$$r_{1S}a^2 = \frac{0.87 l_c}{A}\cdot\frac{K_{WM}^2 C_M^2}{C_S K_{WS}^2} = (r_{1M} + Z_M) \quad (20)$$

or

$$AC_S = \left(\frac{0.87K_{WM}^2 C_M^2}{(r_{1M} + Z_M)}\right)\left[\frac{l_c}{K_{WS}^2}\right] \quad (21)$$

The terms in parentheses all apply to the main winding and are not subject to change. The terms in brackets are fixed by the starting winding distribution but are independent of the number of starting winding turns. Hence, the right-hand member of this equation is a constant for a given starting winding distribution. The product AC_S represents the circular mils per conductor times the number of starting winding conductors or the total useful slot area devoted to starting winding. Hence, regardless of the various combinations of turns and wire sizes, if they result in maximum windings, the total slot areas required for the starting windings are identical.

Or, if the total slot area for starting windings is fixed by heating considerations or otherwise, the maximum winding becomes fixed as indicated previously. This does not preclude the possibility of obtaining a winding which is apparently better than the maximum winding if the slot area for the starting winding is allowed to vary. This point is illustrated in the discussion of the table of results which is presented later.

This conclusion is based on a fixed distribution for the starting winding. In

case the total area given by equation 21 is too large, can any other distribution result in a satisfactory maximum winding which requires less slot area? To investigate this, it is first necessary to derive the expression for the slot area required for the largest starting winding coil.

Circular mils of copper for the fullest starting winding coil

$$= [0.87 K_{WM}{}^2 C_M{}^2/(r_{1M}+Z_M)]\,[I_e/K_{WS}{}^2 S'] \quad (22)$$

where S' is the equivalent number of full slots for the starting winding. (Thus, if a four-pole 36-slot motor had a winding distribution for the starting winding of two 100 per cent coils and two 50 per cent coils under each pole, S' would be 24.) The terms in brackets are all functions of the distribution. If it is assumed that Appleman's[3] distributions for sinusoidal space waves are used, the bracketed quantity varies from 1.20 to 0.70 for the range investigated. The smaller quantity resulted from a wider distribution. Hence, we can conclude that, as more coils per pole are used, the maximum winding required less slot area.

Vector Relationships

The starting torque varies directly as the sine of the time angle between the starting and main winding currents. Refer to Figure 1. From equations 16 and 17, it is obvious that

$$\text{Sin}\,\theta_t = \frac{X_M}{\sqrt{2Z_M(Z_M+R_M)}} \quad (23)$$

$$\text{Cos}\,\theta_t = \frac{Z_M+R_M}{\sqrt{2Z_M(Z_M+R_M)}} \quad (24)$$

Since these terms are all functions of the main winding, it follows that for all maximum windings the angle θ_t is fixed. Then as r_{1S} and a^2 are varied (keeping the same product), the point p moves from $p_1 = 0$ to $p_2 = \infty$ as in Figure 2.

Starting Currents

The total starting current is:

$$I_T = \sqrt{(I_S \sin\theta_t)^2 + (I_S \cos\theta_t + I_M)^2} \quad (25)$$

or in terms of winding constants for maximum windings:

$$I_T = V\sqrt{\frac{a^4}{2Z_M(Z_M+R_M)} + \frac{1+a^2}{Z_M{}^2}} \quad (26)$$

The current in the starting winding is:

$$I_S = \sqrt{I_T{}^2 - I_M{}^2 \sin^2\theta_t} - I_M \cos\theta_t \quad (27)$$

Since each maximum winding will require a different total starting current and this current is limited usually by design specifications, it is useful to determine the ratio of transformation which will yield a required number of starting amperes. This can be obtained by solving equation 26 for a^2. Thus:

$$a^2 = \sqrt{2Z_M(Z_M+R_M)} \times \frac{\sqrt{I_T{}^2 - I_M{}^2 \sin^2\theta_t} - I_M \cos\theta_t}{V} \quad (28)$$

A simpler method of determining a for a given starting torque is shown later.

Starting Torque Per Ampere

Faced with a limit on starting current and a starting torque value which must often be kept high, the starting torque per ampere of starting current is an important figure. For all of the maximum windings which the designer can apply to a given job, the question naturally arises as to whether any proposed winding is producing as much starting torque as is possible for the limiting current. For that reason an investigation of the conditions for maximum starting torque per ampere is of interest.

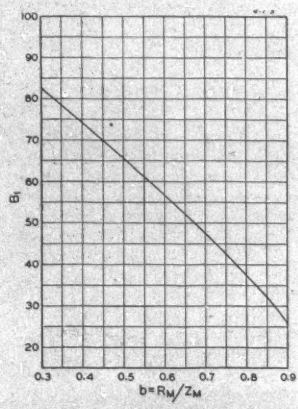

Figure 3. Constant for calculating starting torque

Equation 18 expresses the torque obtained from a maximum winding. For simplicity, the square of the total starting current will be used in setting up the ratio. Then from equations 18 and 26

$$\frac{\text{St.T}}{I_T{}^2} = \frac{112.7 r_{1S}}{\text{Syn. rpm}} \cdot \frac{2X_M}{2(Z_M+R_M)(1+a^2)+Z_M a^4} \quad (29)$$

When this is differentiated with respect to a and the result equated to zero, the maximum value for equation 29 is obtained. For this condition:

$$a^2 = \frac{(Z_M+R_M) + \sqrt{(Z_M+R_M)^2 + 6Z_M(Z_M+R_M)}}{3Z_M} \quad (30)$$

Working Curves

The formulas given up to this point can be simplified and the results plotted into useful curves by employing the ratio of constants R_M/Z_M. Let

$$b = R_M/Z_M$$

Then equation 18 becomes

$$T = I_M{}^2 \frac{ar_e}{\text{Syn. rpm}} \left[\frac{112.7\sqrt{1-b^2}}{1+b}\right]$$

The quantity in brackets is plotted for a range of b values and is designated B_1. This is of value in determining the starting torque after a has been selected. See Figure 3.

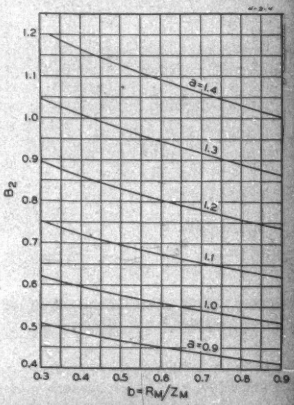

Figure 4. Relation between current in starting and current in main windings

The ratio of currents in the two windings:

$$I_S/I_M = Z_M a^3/\sqrt{2Z_M(Z_M+R_M)}$$

If the b ratio is used, this can be expressed:

$$I_S/I_M = \left[\frac{a^3}{1.41\sqrt{b+1}}\right]$$

The quantity in brackets will be designated B_2 and is plotted for a range of values of b in Figure 4. This is useful for determining the starting winding current after a has been selected.

To determine the ratio of transforma-

tion required to produce a given total current the following ratio is useful:

$$I_T/I_M = \sqrt{\frac{a^4}{2(b+1)} + 1 + a^2}$$

The right-hand member, designated B_3, is plotted in Figure 5.

The equation for the ratio of transformation which gives the maximum torque per ampere squared can be rewritten:

$$a = \left[\sqrt{\frac{(1+b)+\sqrt{(1+b)^2+6(1+b)}}{3}}\right]$$

The quantity in brackets, designated B_4, is plotted in Figure 6. This is so nearly a straight line that we can assume

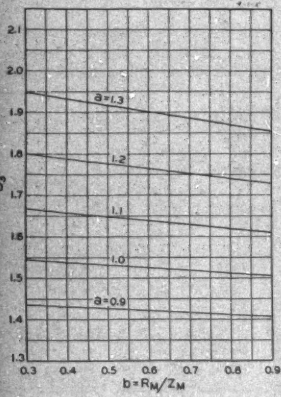

Figure 5. Relation between total current and current in main winding

it to be such for a useful approximation. It follows that the maximum torque per ampere is obtained for any maximum winding if the ratio of transformation is:

$$a = 1.12 + 0.3(R_M/Z_M)$$

Procedure

In the process of designing the starting winding for split-phase motors it is suggested that the curve data be used in the following manner. The main winding has been determined, and the constants have been calculated. Perform the operations listed.

(*a*). $I_M = V/Z_M$, $b = R_M/Z_M$.

(*b*). Select the starting winding distribution.

(*c*). Calculate K_{WS}, l_c, and S'.

(*d*). As a check, determine if the slot area provided for the starting winding is sufficient for a maximum winding (equation 22).

(*e*). If the starting current is the critical factor, use the allowable I_T and calculate I_T/I_M. Read the allowable value of a from Figure 5 which will yield this current. The a used can be less but should not be more than this value.

(*f*). For the chosen value of a, calculate the starting torque from

$$T = I_M^2 \frac{ar_b}{\text{Syn. rpm}} B_3$$

(*g*). If the current and torque are satisfactory, determine the starting winding conductors,

$$C_S = \frac{K_{WM} C_M}{K_{WS} a}$$

(*h*). Determine the nearest wire size to yield r_{1S}.

(*i*). Calculate I_s from $I_M B_3$ of Figure 4; determine circular mils per ampere.

(*j*). Investigate if desirable, the effectiveness of the winding by comparing the a used with the a which would yield the maximum torque per ampere.

Corrections

Some designers may find it feasible to correct the starting torque equation by a factor taking into account the rotor bar skew and harmonic effects. Such a correction has been neglected here as not being germane to the development given.

It will be noted that all resistances are given for 25 degrees centigrade. This point requires some comment. From the standpoint of calculating starting currents pessimistically, the "cold" value is recommended. Temperature increase will reduce the current; hence, this method is conservative. As to the temperature effects on starting torque, an increase in resistance may reduce the current and the starting torque enough to yield less torque than desired. Temperature increase of the rotor and the starting winding may be opposite in their effects. Rapid heating of the starting winding usually occurs; it is practically impossible to predetermine with any accuracy the temperature at which starting winding and rotor winding will be operating by the time several starting torque tests have been taken. There is also some evidence that a slight skin effect is present in the rotor bars, giving a higher apparent resistance. All of these factors cause discrepancies between calculated and test values. In general, experience indicates the extent of the mental reservations with which the designer must examine calculated performance.

Typical Values

In the usual design of 60-cycle single-phase motors, the ratio of resistances to total leakage reactances is somewhat as follows:

$r_{1M}/X_M = 0.3$ to 0.4 $\quad r_b/X_M = 0.3$ to 0.4

Substituting these values, we find that $(r_{1M}+Z_M)$ usually will be from 1.56 to 1.75 times X_M. For maximum windings this fixes the angles within limits, yielding values as shown in the following:

$r_{1M}/X_M = r_b/X_M = 0.3$	$r_{1M}/X_M = r_b/X_M = 0.4$
$\theta_M = 59° 2'$	$\theta_M = 51° 20'$
$\theta_S = 30° 50'$	$\theta_S = 26° 17'$
$\theta_i = 28° 12'$	$\theta_i = 25° 3'$
$\theta_s/\theta_M = 0.52$	$\theta_s/\theta_M = 0.51$

Example: A starting winding is to be designed for a motor rated at one-eighth horsepower, 60 cycles, 1,150 rpm, 115 volts. The following constants are known:

$r_b = r_b K_T = 4.85$	$Z_M = 14.1$
$r_{1M} = 4.41$	$b = 0.657$
$R_M = 9.26$	$r_{1M} + Z_M = 18.51$
$X_M = 10.7$	$I_M = \frac{V}{Z_M} = 8.17$
$C_M = 1,248$	
$K_{WM} = 0.856$	

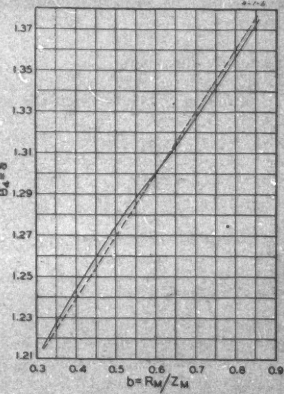

Figure 6. Ratio of transformation required for maximum torque per ampere squared

The starting winding is to be designed to yield a starting torque of 15 ounce-feet without exceeding 15 amperes of starting current. (Lettered items identify the steps previously given in the procedure.)

(*b*). A starting winding distribution will be selected for which

(*c*). $K_{WS} = 0.837$ $\quad l_c = 4.45$ $\quad S' = 24$ slots

(*d*). From equation 22, it is seen that 14,200 circular mils of slot area might be needed. Adequate space has been provided in the slot so that the fullest starting winding coil can have this value of useful copper cross section if required.

(*e*). $I_T/I_M = 15/8.17$ or 1.85

From Figure 5

$a = 1.27$

This is the ratio of transformation which will yield a starting current of 15 amperes.

(*f*). Read B_1 from Figure 3 as 51.2.

$$T = 8.17^2 \frac{1.27 \times 4.85}{1{,}200} \cdot 51.2 \text{ or } 17.5 \text{ ounce-feet}$$

Since only 15 ounce-feet of starting torque are required, some leeway can be used in the number of turns (reducing rather than raising a) and in the starting winding wire size. If need be, a could be as low as $15/17.5 \times 1.27$ or 1.09.

(*g*). The starting winding conductors:

$$C_S = \frac{0.856 \times 1{,}248}{0.837 \times (1.27 \text{ to } 1.09)} = 1{,}010 \text{ to } 1{,}170$$

Conductors in the fullest slot will be:

$$C_S/S' = \frac{1{,}010 \text{ to } 1{,}170}{24} = 42 \text{ to } 48.7$$

The minimum value yields the highest starting torque.

(*h*). The wire size can be determined readily by several different methods, but, since item *d* has shown that the circular mils per slot should be 14,200, the circular mils per conductor are obviously:

$14{,}200/(42 \text{ to } 48) = 349 \text{ to } 295$

Use number 25 with a cross section of 320 circular mils.

This will yield a starting winding resistance of from 12.1 to 14.0 ohms, depending upon the number of turns used. To satisfy the relationship of equation 14 the resistance should fall between 11.4 to 15.5 ohms with the variation in turns. We might assume that 44 turns will be used in the fullest coil, giving C_S a value of 1,056. Then $a = 1.21$ and $r_{1S} = 12.7$.

Since

$$r_{1S} = 1/a^2(r_{1M} + Z_M)$$

is still satisfied by this choice, the final winding is a maximum winding. Some leeway usually can be tolerated in this final check.

(*i*). The starting winding current:

$I_S = I_M B_1 = 8.17 \times 0.80$ or 6.53.

B_1 is read from Figure 4. The circular mils per ampere $= 320/6.53$ or 49.

(*j*). To check the design against the maximum starting torque per ampere, use B_4 in Figure 6, or calculate. Then $a = 1.12 + 0.3 \times 0.657$ or 1.317. From this viewpoint the winding could be more effective.

The final value of starting current is 14.4 amperes, yielding a starting torque of 16.8 ounce-feet.

Conclusions

The advantages and disadvantages of this design procedure are well illustrated by the numerical example and table of results. The use of the maximum-winding method and the accompanying curves yield at once the desired performance items. The tabulated results of the sample design are shown in column 1 of the table. As a further investigation the resistance of the starting winding was arbitrarily increased for the calculations of column 2, and decreased for the calculations of column 3. Both changes showed a decrease in starting torque, illustrating that the maximum winding yields a true maximum of torque as previously indicated. Yet the actual change in torque is small, which indicates that the curve of torque versus starting winding resistance, under the other conditions maintained in this method, is comparatively flat. This is a useful fact, for it gives the designer some choice in starting winding conductor cross section without serious interference with final results.

As pointed out previously, many combinations of windings might yield the desired results. An example of this is seen in column 4. By trial and error, with the use of a different ratio of transformation, a winding was obtained to satisfy the limiting conditions, even though it was not a maximum winding. When the same number of conductors was adjusted in resistance until it resulted in a maximum winding, the design specifications were no longer met. These results are shown in column 5. It should not be concluded that the calculation of another winding to yield the desired results upsets the advantages of the procedure shown here. Such a winding was obtained only by a lengthy trial-and-error process, with each step calculated without the benefit of the labor-saving curves resulting from maximum winding procedure. Furthermore, it will be noticed that such a winding is obtained without regard to the conditions set up as to the slot space to be utilized for starting winding conductors.

Table I. Contrasted Results

	1	2	3	4	5
Conductors, starting winding	1,056	1,056	1,056	850	850
Ratio a	1.21	1.21	1.21	1.5	1.5
Resistance, starting winding	12.7	16.0	10.0	12.7	8.22
Starting torque, ounce-feet	16.80	16.10	16.15	19.2	20.6
Total starting amperes	14.4	13.3	15.45	13.96	17.9
Starting winding amperes	6.53	5.55	7.55	7.4	10.13
Torque per ampere	1.165	1.208	1.042	1.286	1.15
Circular mils per ampere	49	47	55.4	34.9	39.6
Comment	Maximum winding	r_{1S} too large	r_{1S} too small	New a, new trial design	New a, maximum winding

List of Symbols

r_{1M} = the resistance of the main stator winding

r_{1S} = the resistance of the starting winding

r_2 = the rotor resistance in main winding terms

r_0 = the corrected rotor resistance in main winding terms $= K_r r_2$

$R_M = r_{1M} + r_0$

$R_S = r_{1S} + r_0/a^2$

a = ratio of transformation, main to starting windings

X_M = total main winding leakage reactance, stator and rotor, in main winding terms

X_S = total starting winding leakage reactance, stator and rotor, in start winding terms

Z_M = total impedance, main winding and rotor

Z_S = total impedance, starting winding and rotor

$K_r = \dfrac{X_0 - X_M}{X_0}$ (all main winding terms)

X_0 = total magnetizing and primary leakage reactance

I_M = current in main winding, rotor blocked

I_S = current in starting winding, rotor blocked

I_T = vector sum of I_M and I_S

θ_M = time angle of lag, V and I_M

θ_S = time angle of lag, V and I_S

θ_t = time angle, I_M and I_S

C_M = series turns, main winding

C_S = series turns, starting winding

K_{WM} = winding factor, main winding

K_{WS} = winding factor, starting winding

l_c = average length of starting winding conductor, in inches

A = cross section of conductor in circular mils

S' = effective number of full stator slots, using the largest number of turns in any starting winding coil as 100 per cent

$b = R_M/Z_M$

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Some Aspects of Electric-Motor Design — Polyphase-Induction-Motor Design to Meet Fixed Specifications

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A CURIOUS gap exists in the technical literature dealing with electrical-design methods. Procedures for determining performance by various analyses and for various testing methods can be found on nearly all of the more common machines. Yet the novice or the intelligently curious, interested in the field of design, finds but few references in the technical literature concerning the procedure whereby the machine dimensions were first determined and the completed design made. While it is true that a comparatively small group of engineers may be concerned with such design work, the philosophy and technique of approach could be of interest to an entire profession which is so profoundly influenced by the designer's work.

It is the purpose of this paper to examine the task of the electrical designer and the modern approach to his problems. Because the field is too large for generalities to be understood readily in their complete significance, the polyphase induction motor, only, will be considered. This field is covered in print, to a limited extent, by reference or text books on design. The point of view, so presented, will first be analyzed to determine how adequately it meets the requirements of the design engineer, and an additional approach will be suggested. This is in no way intended as a minute and detailed exposition of electrical design but rather a point of view from which the designer operates, with illustrative examples.

The first step in considering the design of a polyphase motor is a matter of definition. A motor has a certain rating because

1. At that rating, the breakdown torque is at least a certain minimum percentage of the full-load torque.
2. The starting torque is a certain minimum percentage of the full-load torque.
3. The locked-rotor amperes do not exceed a certain definite value.
4. The full-load temperature rise does not exceed a definitely fixed value.

For general-purpose motors or some groups of special motors, these specifications are fixed by standardization. However, no recent standards are available on item 3 aside from the requirements of power companies, and the old National Electric Light Association rules, which appear to be considered rather generally by the motor industry.

Only the addition of limits on full-load slip are needed to complete the list of important motor characteristics which must be met by a successful design. Even with no standards at present pertaining to this item, it is limited largely through having to deal with a competitive market. The same might be said of practically all items concerning motor performance. The type of application, the specifications set by the customer, or the general understanding as to what is acceptable commercial practice are all of such importance that, even with no standardization on any of these items, in effect they are all fixed either exactly or between limits.

With known values of these characteristics required of the completed design it would appear that a satisfactory design procedure would incorporate methods whereby the characteristics could be achieved. It is interesting at this point to examine the process most commonly published for initiating a design, namely, the use of the D^2L formula. This takes a form about as follows:

$$D^2L = \frac{\text{horsepower}}{\text{rpm}} \times \frac{K}{B_g \times \text{power factor} \times \text{efficiency} \times q}$$

wherein

D = rotor diameter in inches
L = axial length of the rotor stack in inches (assumed equal to the stator stack)
K = a constant
B_g = flux density in the gap
q = ampere conductors, stator or rotor, per inch of periphery

This formula is theoretically correct. For any given design, if the correct values are substituted in the right-hand member, it yields a calculated value of D^2L in agreement with the physical facts. But it is when the process is applied in the form for which it is intended that some ambiguity exists. Consider the terms making up the formula.

The average gap density, B_g, may fall between limits of 30,000 to 40,000 lines per square inch for 60-cycle motors, according to various writers. Actually this may be influenced by a number of factors. These would involve the proportion of tooth and yoke areas in the stator and also the rotor laminations. The radial length of air gap has some influence also, for higher gap densities are usually avoided on motors in which the stator bore is not ground after construction. These all influence magnetic side pull and hence reduce the allowable gap density. In light of these facts, considerable variation in the density is logical and inevitable.

The full-load power factor and efficiency are required in the equation. These are also terms which are subject to some variation, although not over so great a range. Suppose we select a 25-horsepower, 1,725-rpm general-purpose motor as typical. From different sources we obtain values as follows:

Power factor	0.900	0.89	0.958	0.935	0.87	0.890
Efficiency	0.905	0.90	0.910	0.890	0.89	0.895
Apparent efficiency	0.8145	0.801	0.8718	0.832	0.774	0.7965

These represent two published sources and four tests of different manufacturers' motors.

The remaining term, q, involving ampere conductors, is one of the chief causes for uncertainty in this equation. It is related to circular mils per ampere and may appear in conjunction with other terms as "electric loading." Ultimately, it is intended to give a measure of heating or to control the temperature rise of the motor. Now if the D^2L equation is expected to be widely useful, it is to be assumed that considerable data on probable values of q for standard open motors,

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enclosed motors, intermittent ratings, and so forth should be available. Actually, suggested values are nonexistent except for a few average curves.

It was approximately six years ago, that the writer's interest in the D^2L equation and the q factor was aroused to the extent of starting an active file on the subject. Since then, the calculated values of q from various motors, representing a wide range of manufacturers, have been accumulated. The results have been both astonishing and worthless. Even though such types as totally enclosed, totally enclosed fan-cooled, intermittent ratings and 25-cycle designs are segregated, no possible curves for suggested values of q versus horsepower could be drawn through the several hundred points obtained. One cause of discrepancy is the fact that while one group of motors was nominally 40 degrees centigrade rise, the actual temperature rise at full load for such motors varied from 19 degrees centigrade to 45 degrees centigrade. Typical values for the 25-horsepower rating previously mentioned were 635-, 790-, and 885-ampere conductors per inch for three motors, against 500 and 710 from reference-book recommendations.

More must be said about electric loading, but let us first take stock of the influence of these factors. It must be kept in mind that the whole purpose of the traditional design process is to assume reasonable values for these factors, to substitute in the D^2L equation and thereby to determine the armature dimensions for the given horsepower and speed. Let us consider the 25-horsepower rating, determine D^2L, using the lowest values of the factors, and recalculate, using the highest values of all terms as recommended or found on actual designs. Granted that this may be an extreme procedure, the results are none the less surprising. The designer is thereby offered a choice of approximately 2.6 to 1 for the rotor volume. In short, if he has selected say ten inches for the rotor diameter, the D^2L equation has "fixed" the lamination stack between approximately 2.5 to 6.0 inches. One does not need to be a very experienced designer to be able to estimate this closely and avoid the nuisance of calculation.

Having gone through the calculation of the required D^2L for a given horsepower and speed, it is well to re-examine those first items by which the motor has been defined. To repeat, a motor has a certain rating only because its maximum torque, its starting torque, its starting amperes, its temperature, and its slip are within certain limits. Yet one finds no such items directly in the D^2L process, and one is forced to the conclusion that this design approach has initiated a design procedure with no regard to the items by which the design is defined. Several more subtle difficulties are present. When q has been chosen for the design calculations, the number of conductors on the winding are thereby fixed, except for the possible changes of D relative to L. Working with a selected value of flux density and a relatively fixed number of ampere conductors per inch may fix the maximum torque but with no regard to the desired value. The final design may readily be one in which the chosen proportions actively prevent the designer from obtaining a characteristic demanded of the motor.

Of all the terms in the D^2L equation, only one is assumed to be concerned directly with a desired characteristic. This is q, which, as a measure of electric loading, is intended to assure a safe value of temperature rise. Unfortunately, experience tends to minimize the importance of electric loading rather than emphasize it. *Motor ventilation introduces an important factor which is taken into account in no design process.* Yet its effect is equally important, if not more important, than electric loading.

The design office with which the writer is connected has just completed a new series of motors in which a thorough investigation has been made of motor air delivery, velocity through the ventilating ducts, and air-flow paths. (All attendant heat runs were made by thermocouples, located at various positions throughout the winding and on the core surface.) Conclusions, extreme as they may appear, can be summed up about as follows: A design using say 300 circular mils per ampere in the stator winding, with correct ventilation, may display lower temperature rise than one with 600 circular mils per ampere and ineffective ventilation. The correct design of a cooling fan, or of baffles used with the fan may have more effect on motor heating than a 75 per cent or even 100 per cent change in electric loading. On totally enclosed motors the use of properly located fans and in some cases fins to break up the vortex caused by these fans, may make a difference of from 20 to 30 degrees centigrade on the temperature of the stator copper.

If the classical theory for initiating a motor design is inadequate for meeting the specifications of a competitive market, by what method is a motor designed? Before attempting an explanation, it is informative to look at the next steps which tradition has given us for the design procedure. These are

1. The design of the laminations and windings, using the rotor diameter and stack as determined by the D^2L equation.
2. The calculation of winding constants.
3. The determination of performance.

Note in this process that the defining items, determining the success of the design, cannot be calculated until the design is finished. Failure calls for extensive redesign. Let us modify this traditional point of view, setting up a new criterion for a successful design method, namely, an ideal method for design is one built around a set of equations in which it is possible *to supply the desired characteristics* and solve for the physical constants. Note that this is a direct approach to the defining items.

Following this procedure, a polyphase induction motor could be designed by selecting any one of the defining characteristics as a means of determining motor proportions and windings. But the process is greatly simplified if these are fixed by maximum torque.

The maximum torque is influenced by only two of the winding parameters, stator winding resistance, and total leakage reactance. Once it is used to determine these winding parameters, in conjunction with the rotor resistance, it fixes

(*a*). Locked-rotor amperes.

(*b*). Starting torque.

(*c*). Full-load slip.

For these reasons the design process will be set up on the assumption that motor proportions and stator winding are fixed by the required maximum torque of the motor.

An electric motor consists of both a magnetic and an electric circuit. Theoretically, both need to be designed; actually, in the great majority of cases the contour (if not the area) of the magnetic circuit is fixed. This is because the motor industry may sell horsepower but actually sets up to manufacture frames. Into these frames certain laminations can be built, and once the dies for producing them have been made, economy demands as wide a use of these laminations as possible. Changes in winding specifications represent no such investment, and hence the designer is constantly under the economic pressure to build as many ratings as practicable in the same laminations, achieving the desired characteristics by control of the electric circuit.

For these reasons the first example of design process shown here will be based on the assumptions that the laminations are already designed and that the stack has been chosen. In short, this is design in a fixed magnetic circuit, using a predetermined or fixed radial length of air gap.

The Maximum-Torque Equation

The equations to be used in these analyses will be based entirely on the approximate equivalent circuit for the three-phase induction motor. The writer does not consider them accurate enough for high-grade design work, but in this paper we are interested in the principles involved and do not want to complicate the approach by a series of corrections necessary to the concepts of the exact circuit representation.

On such a basis, a common equation for maximum torque is:

$$T_m = \frac{7.05}{\text{Syn. rpm}} \frac{nE^2}{2[R_1 + \sqrt{R_1^2 + X^2}]} \quad \text{pound-feet} \quad (1)$$

The first requirement is to obtain, not torque in terms of circuit constants, but circuit constants in terms of torque. Then

$$R_1 + \sqrt{R_1^2 + X^2} = \frac{7.05nE^2}{2(\text{Syn. rpm})T_m}$$

There are two winding constants in this equation. It is difficult to obtain a winding in terms of both R_1 and X, and for simplification we will make use of the ratio α, defined as R_1/X. Now

$$T_m = \frac{7.05nE^2}{2(\text{Syn. rpm})X} \left[\frac{1}{\alpha + \sqrt{\alpha^2+1}} \right] \quad \text{pound-feet} \quad (2)$$

or

$$X = \frac{3.52nE^2\beta}{\text{Syn. rpm}\, T_m} \quad (3)$$

where

$$\beta = \frac{1}{\alpha + \sqrt{\alpha^2+1}} \quad (4)$$

There are two facts connected with this transformation which are highly important.

1. Through equation 3 we obtain an expression for the reactance of the winding to yield a required value of maximum torque.

2. This expression no longer contains the term R_1 but merely the ratio of R_1/X.

The ratio of stator winding resistance to total leakage reactance is independent of the winding for a fixed stack. This ratio is a function of the lamination design and is constant except for the slight change brought about through winding pitch. It is upon this fact that the entire simplification of the design process depends.

It is now only necessary to obtain an expression for leakage reactance in terms of stator conductors to determine directly the winding necessary for a required value of maximum developed torque.

To follow these steps in more detail:

Resistance of the Stator Winding. If the area of each stator slot is A circular mils, of which the decimal fraction k is useful, the total cross-section area of copper available per phase is

$$\frac{AkS_1}{n} \quad \text{(circular mils)} \quad (5)$$

If l_t is the average length of conductor, the resistance of all copper per phase, with the slots full and all of the conductors in parallel, is

$$\frac{l_c n}{AkS_1} \text{ (ohms)} \quad (6)$$

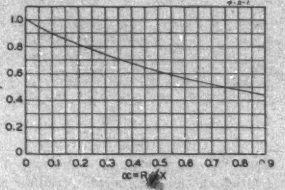

Figure 1. Correction for stator resistance drop

Split up into C series conductors, the resistance of the winding per phase at 60 degrees centigrade will be

$$R_1 = \frac{l_c n}{AkS_1} C^2 \quad (7)$$

Leakage Reactance, Stator and Rotor. The form to be used for this equation is

$$X = 2\pi f C^2 n \mathcal{P} 10^{-8}$$

wherein $\mathcal{P}$ is the permeance of the leakage paths for both stator and rotor, corrected for pitch.

The equation

$$\frac{R_1}{X} = \frac{l_c \times 10^8}{2\pi f A k S_1 \mathcal{P}} \quad (8)$$

is the development of the statement made previously concerning this ratio. The obtaining of an expression for winding resistance as a function of C^2 is shown to be useful by the fact that this eliminates the number of conductors from the ratio, leaving it (as previously mentioned) as a function of the laminations.

When R_1/X is known, it is convenient to obtain β by the curve of Figure 1.

If this is substituted in equation 3, we obtain a value for X, from which it follows that the required series conductors are

$$C = \sqrt{\frac{X \times 10^8}{2\pi f n \mathcal{P}}} \quad (9)$$

The total series conductors Cn will be divided into S_1 slots. The approximate copper area per slot is Ak, and hence the circular-mil area of each conductor is

$$\frac{AkCn}{S_1} \quad (10)$$

This is adjusted to the nearest wire size and the number of parallel paths desired.

We now have the stator winding, both turns and wire size, to give a prescribed maximum torque. When the rotor winding has been calculated, it represents a completed design, except for all of the performance checks which a careful designer may wish to apply. Only one such check will be shown at this point.

Flux Density in the Stator Teeth (Maximum) in Kilolines Per Square Inch.

$$B_t = \frac{70.9EP10^3}{C \times f \times k_w \times t_w \times L \times S_1} \quad (11)$$

Note that the weak point in this method lies chiefly in the fact that the initial steps in design are taken without regard to flux density. Only when the conductors have been determined can the density be checked. This is not often serious for an experienced designer, but it is confusing to the novice. The next step shown eliminates such uncertainty.

Stack Necessary to Produce Required Torque and Density

In the previous analysis the stack was fixed, and the flux density for the required design was determined only as a final check. A method will now be shown whereby the stack and winding will be determined, simultaneously, to yield the required torque in a given set of laminations. The problem is complicated by the fact that there exists no simple relationship between maximum torque and stack for a fixed flux density. Note that the maximum torque depends upon both R_1 and X. As the stack varies, R_1 becomes a function of a changing length of conductor, one portion of which (the embedded part) varies as the stack; the end-coil length is fixed for all stacks. Also, as the stack varies, two components of X (the slot and zigzag components)

vary directly, while the end-leakage component remains independent of stack.

The resultant variation of torque with stack depends upon the relative values of these components in any design.

Now if it were possible to divide an electric motor into two imaginary parts, one made up only of the stacking and the constants resulting from the embedded conductors, and the other made up of the winding constants resulting only from the end coils, the former part would yield a

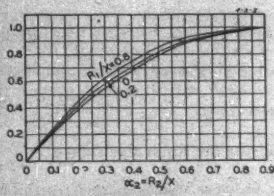

Figure 2. The ratio ϵ represents starting torque divided by maximum torque

torque as a simple function of stack. It would then be possible to vary the stack until the required flux density was achieved, adding the influence of the "end" motor to obtain the over-all performance.

A polyphase induction motor can be so divided, and we can write:

For a fictitious "stack" motor, having no end coils

$$T_{ms} = \frac{7.05nE^2\beta_s}{2(\text{Syn. rpm})X_s} \tag{12}$$

where X_s is made up of slot and zigzag leakage components only; β_s is the relation of equation 4 resulting from the embedded portion of the conductors.

For a fictitious "end" motor

$$T_{me} = \frac{7.05nE^2\beta_e}{2(\text{Syn. rpm})X_e} \tag{13}$$

where X_e is the end leakage only, β_e is the relation shown in equation 4, using end leakage and resistance of end coils only.

The actual maximum torque of a motor in terms of the two fictitious components is

$$T_m = \frac{T_{ms}T_{me}}{T_{ms}+T_{me}} \tag{14}$$

This relationship is useful because, when expanded, it can be solved directly for stack. As a first step, from equation 14

$$T_m = \frac{3.53nE^2\beta_s\beta_e}{(\text{Syn. rpm})(X_s\beta_s+X_e\beta_e)}$$

To expand to permeances

$$2\pi fC^2n10^{-8}[\mathcal{P}_s\beta_s+\mathcal{P}_s'L\beta_e] = \frac{3.53nE^2\beta_s\beta_e}{\text{Syn. rpm}\times T_m} \tag{15}$$

When the expression for stator tooth density shown in equation 11 is used, it follows that the required number of conductors are

$$C = \frac{1}{L}\left[\frac{EP}{B_{ef}}\cdot\frac{70.9\times10^8}{S_it_wk_w}\right] \tag{16}$$

Let the expression in brackets be C_e and substitute in equation 15:

$$\frac{\mathcal{P}_s\beta_s}{L^2}+\frac{\mathcal{P}_s'\beta_e}{L}-\frac{3.53E^2\beta_s\beta_e\times10^8}{2\pi f(\text{Syn. rpm})C_e^2T_m}=0 \tag{17}$$

To solve for L

$$L = \frac{1}{\sqrt{Q^2+Q_1}-Q} \tag{18}$$

wherein

$$Q = \frac{\mathcal{P}_s'\beta_e}{2\mathcal{P}_s\beta_s} \tag{19}$$

$$Q_1 = \frac{3.53E^2\times10^8}{(\text{Syn. rpm})2\pi fC_e^2T_m}\cdot\frac{\beta_s}{\mathcal{P}_s} \tag{20}$$

This value of L is the stack required to give the desired maximum torque, maintaining the desired flux density in the teeth. The series conductors per phase are then determined from C_e/L. If this process appears too complicated, it should be kept in mind that many of the terms used are constant for the laminations and, if recorded with them, need not be recalculated for each design.

We have now reached the same point achieved in the first process and, with the stator winding fixed (by either of the two methods), are ready to complete the design.

Examples

The ideas expounded in the preceding material will be illustrated by an example. The problem is to fix the design of a general-purpose motor rated as three phase, 60 cycles, four poles, 25 horsepower, 220 volts.

The specifications to be met are:

Maximum torque, 210 pound-feet or 275 per cent of full load.

Starting torque, 122 pound-feet or 160 per cent of full load.

Starting kilovolt-amperes per horsepower 4.5 to 5.6.

Full-load slip, not over five per cent.

Temperature rise, 40 degrees centigrade continuous.

The frame in which this motor is to be built has a diameter such that it will accommodate laminations with an outside diameter of 14.75 inches. In effect this is fixed by the fact that the standard National Electrical Manufacturers Association frame for 25-hp 1,750-rpm rating has a mounting height of shaft above base of nine inches, thereby limiting motor diameter to 18 inches. Actually only a lesser dimension is available, still further reduced by the thickness of the shell or frame casing. Of several laminations which might be available, the one selected displays the following data:

Stator

Outside diameter	14.75 inches
Bore	10.0 inches
Slots	48
Tooth width	0.3125 inch
Slot area	0.51 square inch
Slot constant	1.89

Rotor

Outside diameter	9.94 inches
Slots	60
Minimum tooth width	0.182 inch
Slot constant	1.3

Winding factor, for throw of coils (slots 1 to 11), is $k_w = 0.925$.

The first step in the theory involved design in a fixed stack. We will assume at this point that a stack of five inches will be satisfactory. Later the work will be repeated, solving for both stack and winding.

From the data we calculate the following permeances for an assumed pitch of

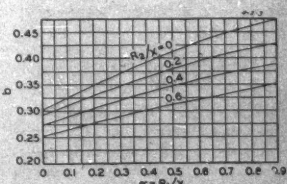

Figure 3. Locked volt-amperes equal 6 times the product of maximum torque and synchronous rpm

83.3 per cent. These are the sum of both stator and rotor values.

Slot permeance	=0.99
Zigzag permeance	=0.655
End permeance	=0.764
Total leakage permeance	=2.409

Note that the leakage reactances dealt with are slot, zigzag, and end components for both stator and rotor. This method can be used regardless of the leakage components preferred. Thus, one may choose to deal with slot, differential, end, and skew components, as calculated by formulas generally available. It is only necessary to modify these formulas

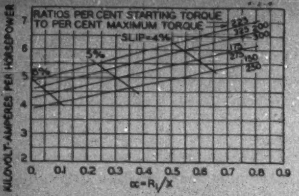

Figure 4. Relation between locked kilovolt-amperes per horsepower, starting torques, maximum torques, and slip for various values of R_1/X

(regardless of their source) until they take the form

$$X(\text{any component}) = 2\pi f n \mathcal{P} 10^{-8}$$

The permeance $\mathcal{P}$ must be corrected for pitch, using such methods as given by Adams or Alger.

To calculate the stator resistance we know that the slot area is 650,000 circular mils of which about 28 per cent can be filled with useful copper.

The length of conductor is calculated to be 16.95 inches, and there are 16 slots per phase. Therefore, the ratio of R_1/X for these laminations is

$$\frac{16.95\times10^3}{2\pi f\times650{,}000\times0.28\times48\times2.409} \text{ or } 0.213$$

By referring to the curve of Figure 1 we find that β equals 0.815, and hence we know that the leakage reactance required to yield a maximum torque of 210 pound-feet is

$$X=\frac{3.53\times3\times127^2\times0.815}{1{,}800\times210} \text{ or } 0.37 \text{ ohm}$$

From equation 9 it follows that the series conductors are 116.

A total of 116 series conductors per phase cannot be wound into similar coils in 48 slots, and hence the actual number used will be 112 conductors resulting from 14 turns per coil.

As the useful slot area is 182,000 circular mils, the area per conductor is 6,500 circular mils requiring the use of number 12 wire in a four-wye circuit.

The stator winding is now fixed both as to number of turns and wire size. The final correct value of R_1/X is still 0.213, X is 0.34, and the maximum torque is 227 pound-feet.

We should still check the flux density, using the stator tooth density as a criterion. From equation 11 we find

$$B_t=\frac{70.9\times127\times4\times10^3}{112\times60\times0.925\times0.3125\times5\times48} \text{ or } 77.2$$

This completes the first part of the design by the method outlined here. It has been a simple, direct process, giving at once a characteristic required by the specifications.

In case, however, that the experienced designer has not been able to estimate the required stacking to give such characteristics, we will illustrate the second method already discussed, whereby the stack and winding are both determined for the maximum torque.

Second Method

The same motor is to be designed with the same laminations, but we will assume at the start that a flux density of 86,000 lines per square inch in the stator teeth will be acceptable. (Values might vary from 75 to 100 kilolines.) The problem now is to determine the stack and the winding.

It is assumed that the following data, pertaining to the laminations as used previously, have been tabulated.

(*a*). The slot permeance (both stator and rotor) per inch of stack for various pitch windings. This will be 0.198 for a pitch of 83.3 per cent.

(*b*). The combined zigzag permeance per inch of stack for various pitch windings and with a fixed radial length of air gap. This will be 0.131 for a pitch of 83.3 per cent. The sum of slot and zigzag permeances will be designated at $\mathcal{P}_s'$ and equals 0.329 for this example.

(*c*). The combined end-leakage permeance for various winding pitches. For the example, this is 0.764.

(*d*). The resistance of a fictitious conductor, equal in area to the total cross-sectional area of all slots per phase, and one inch in length.

(*e*). The length of end connection of one conductor for various throw of coils.

(*f*). The resistance of a fictitious conductor, equal in area to that of item *d* but equal in length to the end connections of item *e*.

From such tabulated data it is necessary to determine R_1/X for the stack motor:

$$\frac{R_1}{X}\text{(stack)}=\frac{10^8}{2\pi f A k S_1 \mathcal{P}_s'}$$

$$=\frac{10^8}{377\times180{,}000\times48\times0.329} \text{ or } 0.0935$$

R_1/X for the end motor is

$$\frac{l(\text{end})10^8}{2\pi f A k S_1 \mathcal{P}_e}=\frac{11.95\times10^8}{377\times180{,}000\times48\times0.764}$$

or 0.478

Refer to Figure 1 and obtain

$$\beta_s=0.63;\ \beta_e=0.914$$

From equation 16

$$C_e=\frac{127\times4}{80\times60}\cdot\frac{70.9\times103}{48\times0.3125\times0.925} \text{ or } 540$$

Calculate

$$Q=\frac{0.329\times0.63}{2\times0.76\times0.914} \text{ or } 0.149$$

$$Q_1=\frac{3.53\times127^2}{1{,}800}\cdot\frac{10^8}{377\times540^2\times210}\cdot\frac{0.63}{0.764}$$

or 0.103

From equation 18 $L=4.56$ inches

This can be rounded off to 4.5 inches.

The series conductors per phase are C_e/L or 120.

This needs no adjustment, as it results in uniform coils of 15 turns each. Using number 12 wire provides a tight but usable winding, increasing the circular mils of copper per slot to 197,000. The correct value of R_1/X is then 0.207; β is 0.814, and the maximum torque is 212 pound-feet.

Fixing the Rotor Resistance

Only one winding constant remains for determination, namely the rotor resistance. This will determine in part the starting torque, the starting amperes (or starting kilovolt-ampere per horsepower) and the full-load slip. Since all of these characteristics are determined by the value of R_2 it is obviously impossible to obtain, say, certain values of starting torque and then expect to obtain, independently, values of slip or starting amperes. Their interdependence prevents such wide choice.

In the analyses which follow we will see how rapid checks on the practicability of the characteristics can be obtained readily and the rotor resistance chosen.

Starting Torque

Using the approximate equivalent circuit, the starting torque is

$$T_s=\frac{7.05}{\text{rpm}}\cdot\frac{nR_2E^2}{(R_1+R_2)^2+X^2} \qquad (21)$$

The ratio of starting torque to maximum torque will be

$$T_s/T_m=\frac{2R_1\left[R_1+\sqrt{R_1^2+X^2}\right]}{(R_1+R_2)^2+X^2} \qquad (22)$$

If this is set up in terms of the ratios, $R_1/X=\alpha$ and $R_2/X=\alpha_2$, we obtain a relationship such that

$$T_s=aT_m \qquad (23)$$

where

$$a=\frac{2\alpha_2\left[\alpha+\sqrt{\alpha^2+1}\right]}{(\alpha+\alpha_2)^2+1} \qquad (24)$$

This is plotted in Figure 2.

Note that the first steps in this process have fixed R_1/X and the maximum

torque. Hence, with the starting torque chosen, the use of these curves immediately fixes R_3/X and hence R_3.

Starting Kilovolt-Amperes Per Horsepower

Since this ratio gives a measure of the starting current, it is subject to power-company limitation. A series of bands has been set up as standard by NEMA each range being designated by a code letter to appear on the motor name plate. In general, the starting kilovolt-amperes have been fixed largely by the maximum torque, although the rotor resistance has some influence. The relationship can be derived as shown below:

$$\text{Volt-amperes (start)} = \frac{E^2 n}{\sqrt{(R_1+R_3)^2+X^2}} \tag{25}$$

Ratio

$$\frac{Va}{T_m} = \frac{\text{rpm}}{3.53}\,\frac{[R_1+\sqrt{R_1^2+X^2}]}{\sqrt{(R_1+R_3)^2+X^2}}$$

$$= \text{rpm}\left[\frac{\alpha+\sqrt{\alpha^2+1}}{3.53\sqrt{(\alpha+\alpha_3)^2+1}}\right] \tag{26}$$

The value in brackets is plotted as b in Figure 3. Obviously

$b \times T_m \times \text{rpm} = \text{starting volt-amperes}$

Once R_3 has been chosen by starting-torque considerations, the value of b can be read to determine the volt-amperes at starting.

It is interesting to note that the relationship of equation 26 can be rewritten in the form:

$$b = 0.1835\,\frac{\text{locked kva per hp}}{T_m/\text{full-load torque}} \tag{27}$$

or

$$5.46b \times (\text{ratio of maximum to full-load torque}) = \text{locked kva/hp}$$

By selecting various useful ratios of maximum to full-load torques and starting to full-load torques, it is possible to assume a series of values of R_1/X, thereby fixing the required values of R_3/X. With these known, b can be calculated and the resulting kilovolt-amperes per horsepower determined. Such curves are shown in Figures 4 and 5. While only two sets are shown, they can be prepared readily for any range of values and form an extremely useful tool for the designer.

Full-Load Slip

This value is of special importance in many cases and obviously has been fixed as soon as the maximum torque and rotor resistance are determined. Any fairly accurate check on the probable value is of interest before the final design is completed. To obtain such check it is possible to make use of a derivation based on the following:

The slip at any torque is approximately

$$s = \frac{R_3}{Y+R_3} \tag{28}$$

$$Y = \frac{E^2 n \times 5{,}250}{746 \times T \times \text{rpm}} - 2(R_1+R_3) \tag{29}$$

Using the ratio of maximum to full-load torque, we obtain by substitution

$$Y = \frac{2\times(T_m/T)}{\beta} - 2(R_1+R_3)$$

From this it follows that

$$s = \frac{\alpha_3}{\dfrac{2T_m/T}{\beta} - 2\alpha - \alpha_3} \tag{30}$$

Refer again to the curves of Figures 4 and 5. For each torque ratio chosen, both α_3 and α are fixed, thereby enabling the full-load slip to be determined through equation 30. A few of the slip curves have been added to these figures, and the value of such curves is apparent, as they indicate at once the limitations in design.

Example Continued

Before proceeding with the actual cage design, the required value of rotor resistance will be determined.

Note that a starting torque of 160 per cent is required and that R_1/X is 0.207. Reference to Figure 5 shows by interpolation that the slip would be slightly less than five per cent for these ratios and that the kilovolt-amperes per horsepower is approximately 4.68. These are within the limits set in the specifications. Hence the design is feasible. Had such values been different from the requirements, *no amount of readjustment would have made it possible to have obtained all of these characteristics*. It is often likely that impossible specifications can be written

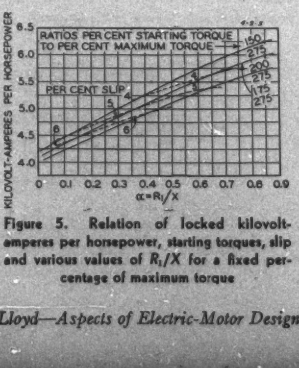

Figure 5. Relation of locked kilovolt-amperes per horsepower, starting torques, slip and various values of R_1/X for a fixed percentage of maximum torque

for simple squirrel-cage polyphase induction motors.

Calculating the ratio of T_s to T_m indicates that a is 0.58. From Figure 2 we find that R_3/X must be 0.30, and hence R_3 is 0.11. This is the value required. A further check on slip by equation 30 indicates that it is 4.96 per cent.

Required Cage Dimensions

Common formulas for rotor resistance differ only in small details. A useful form is

$$\frac{2.4L \times C^3 \times k_w^2 \times 10^{-6}}{S_c \times S_1} + \frac{1.52 D_r C^2 k_w^2 10^{-6}}{S_r \times P^2} = R_3 \tag{31}$$

The first term applies to the bars, the second to the end rings. These are set up for the conductivity of copper and should be multiplied by the appropriate resistivity ratio, if other materials are used.

Because the laminations are already chosen, bar area and length are fixed, with only the resistivity left as a possible variable in some cases. It is therefore necessary to obtain the required resistance by adjustment of end-ring cross section, S_r. Let us call the first term R_b; hence

$$S_r = \frac{1.52\, D_r C^2 k_w^2 10^{-6}}{P^2(R_3 - R_b)} \tag{32}$$

It is necessary to assume the probable end-ring shape or its radial thickness in order that the mean diameter of the end ring, D_r, can be chosen for this solution. Once this is done, all other terms are known, so that equation 32 can be solved directly for the required square inches of area.

Example Completed

The 25-horsepower motor, used as an example, required a rotor resistance of 0.11 ohm in stator terms, to meet the specifications. Slot areas are such that round copper bars having a cross-section area of 0.0655 square inch are used. Hence

$$R_b = \frac{2.4 \times 4.5 \times 120^2 \times 0.856 \times 10^{-6}}{0.0655 \times 60} \text{ or } 0.0338$$

For an assumed average ring diameter of 8.8 inches, each end-ring section is then

$$S_r = \frac{1.52 \times 8.8 \times 120^2 \times 0.856 \times 10^{-6}}{4^2(0.11 - 0.0338)} \text{ or } 0.1348$$

It is customary to check the copper loss in the ring, with the motor stalled, obtaining a value of loss per pound of end-ring material. To keep this to a

reasonable value, it is frequently necessary to use higher resistivity materials. In this case the use of 40 per cent conductivity alloy would increase the section to 0.1348/0.40 or 0.336 square inches.

Summary and Conclusions

In the critical examination made of the D^2L analysis as a basis for polyphase-motor design there are several factors making this process inadequate as a design procedure. It is based on supplying "average" or "reasonable" values which are subject to such variation as to lead to indefinite results. It exercises no direct control over any of the defining factors for the motor rating, except through the electric loading as a measure of temperature rise. Of all of the characteristics on which to base motor proportions, this is the least satisfactory, as temperature rise is so thoroughly dependent upon ventilation and the mechanical design. Finally, no indication of the operating characteristics can be determined until the design work is completed and the winding constants calculated.

In contrast to that process, a design procedure has been set up in this paper, (based on a magnetic circuit of fixed contour) whereby the winding is fixed by direct solution. These equations involve the desired characteristics of the motor and physical constants of the laminations. The simplest approach has been found to be to fix the stator winding by the maximum torque, leaving the end-ring section of the rotor to supply all other performance items. This is a direct process, indicating almost at once whether the performance items can be met. Adjustment of the final design values are usually necessary only through the unfortunately gross steps of the standard wire sizes.

Such a process fits the usual design office requirements inasmuch as the majority of designs are made in laminations already available. Two procedures have been shown; one based on a fixed stack with the disadvantage of no direct control over the resultant flux density, and the other based on the division of the motor into two fictitious parts consisting of a stack motor with no end coil, and an end motor with no stack. The resultant equations make it possible to solve directly for the stack required to obtain a desired maximum torque with a fixed flux density.

The first step in this process is not original with the present writer, having been set up by the late W. J. Branson a number of years ago and used successfully in several design offices. The point of view from which his work was done and the continuation of his work into other parts of the design procedure have not been widespread, if one can judge from the inadequacy of the literature in this field.

On the matter of accuracy, no approximations have been made in any of the derivations except that the torque and current equations are based on the approximate equivalent circuit. The slip calculation does involve a slight approximation, but practice bears out its general accuracy. Bear in mind that it has been the intention in this paper to present a design point of view rather than a highly refined process. As adjuncts to this procedure, it is possible to make corrections in line with the more exact circuit theory, to consider skin effect and temperature change at starting, as well as current distribution in the rotor end rings. Neglect of these would constitute the greatest sources of error as indicated by practice.

Throughout this development the stator and rotor laminations have apparently been neglected although, obviously, their dimensions are of vital importance to the performance. A study of hundreds of laminations makes it possible to formulate some rules for lamination proportions and design. As could be expected from the relation of lamination constants, maximum torque, and densities, laminations of all sizes have an inherent maximum torque. Such data are of importance in attempting to build various powers and speeds in a given frame.

List of Symbols

A—area of one stator slot in circular mils.
a—ratio of starting to maximum torques.
b—ratio of starting volt-amperes to product of maximum torque and speed.
B_g—gap density in lines per square inch.
B_t—maximum tooth density in kilolines per square inch.
C—series conductors per phase.
C_0—series conductors per phase per inch of stack.
D—rotor diameter in inches.
D_r—mean diameter of the end rings in inches.
E—applied volts per phase.
k—fraction of total slot area available for copper.
k_w—winding factor.
l_c—length of conductor in inches.
L—length of stack in inches.
m—number of phases.
P—number of poles.
$\mathcal{P}$—permeance of all leakage paths, stator and rotor.
s—slip as a decimal fraction.
t_w—width of tooth in inches.
T_m—maximum torque in pound-feet.
T_s—starting torque in pound-feet.
T_{me}—maximum torque of "end" motor in pound-feet.
T_{ms}—maximum torque of "stack" motor in pound-feet.
X—total leakage reactance.
X_s—slot and zigzag leakage reactance.
X_e—end turn leakage reactance.
α—ratio R_1/X.
α_r—ratio R_2/X.
β—see equation 4.
$\mathcal{P}_s'$—permeance of slot and zigzag leakage paths, or any components, which vary with the stack.
$\mathcal{P}_e$—permeance of the end leakage flux paths.
R_1—resistance of the stator winding per phase.
R_2—resistance of the rotor cage in terms of stator winding.
R_b—resistance of the rotor bars in stator winding terms.
S_1—number of stator slots.
S_2—number of rotor slots.
S_c—cross-section area each rotor bar in square inches.
S_r—cross-section area each end ring in square inches.

Electronically Controlled Dry-Disk Rectifier

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IN spite of the practically universal use of alternating current for power generation and distribution, there exists an ever-increasing demand for direct current. To obtain direct current from the available supplies of alternating current, means of rectifying the alternating current have been developed. While many types of equipment are available, three types, each supreme in its own range, are found to be in general use for heavy-duty d-c power applications. The mercury arc has proved most efficient for the higher voltages from 250 volts on up. The intermediate range from 60 volts to 250 volts is supplied by the motor generator set. In comparatively recent years the low-voltage range from 0 to 60 volts has been taken over more and more by dry-plate rectifiers.

The dry-plate rectifier was first introduced approximately 30 years ago when the copper-sulfide rectifier was developed. Later in the early 1920's the copper-oxide rectifier was brought out. Recently, in fact during the last four years, selenium-oxide rectifiers have found wide usage in American industry. The selenium rectifier was developed and introduced in Europe in 1928. Continental acceptance of this rectifier has been widespread, for latest estimates indicate that 88 per cent of the metallic-junction rectifiers in use abroad are selenium.

Rectifier Characteristics

The selenium-oxide rectifier has much to offer in the way of stability, efficiency, economy, dependability, compactness, light weight, and ability to take heavy overloads for periods of short duration. Within the lower-voltage range it compares more than favorably with rotating equipment.

Similar to most electrical equipment, selenium rectifiers are designed for a temperature rise in continuous operation of 40 degrees centigrade above an ambient of 35 degrees centigrade. This means that up to the ultimate temperature there is no theoretical limit upon current handling capacity, and, consequently, the rectifier has the ability to handle large overloads for a short interval. The principle components of the selenium rectifier are transformers, selenium stacks, and bussing. These are all static elements, each of which has an indeterminately long life. Because of this freedom from moving parts, bearings, and commutators, the dry-plate rectifier offers completely dependable maintenance-free operation. Selenium stacks readily lend themselves to compact space design and even the largest rectifiers require no foundation.

The low forward resistance and high reverse resistance of the selenium stack combine to give the rectifier excellent economy and efficiency. Power tests show rectifier efficiencies of between 65 per cent and 85 per cent, depending upon the circuit and the load. The forward resistance of the stack is an inverse function of the stack current. Consequently, the I and R loss will tend to remain constant, and the rectifier will maintain high efficiency with unusual consistency from 20 per cent to 150 per cent of full load. In the larger equipment the efficiencies of rotating equipment compare with that of the selenium rectifier at full load, but the efficiency of rotating machinery drops rapidly as the load deviates from full load.

It is only in the matter of control and regulation of the output voltage that the average large selenium rectifier is surpassed by rotating equipment. Normal no-load to full-load voltage regulation for selenium rectifiers is 10 per cent to 18 per cent. While such regulation is satisfactory for most applications, there is still a great number of installations which require closer voltage control and regulation over a wide range. It was to meet this need that the fully automatic electronic control discussed in this article has been developed. The control makes it possible to obtain output voltages constant to one half of one per cent from selenium rectifiers even when the rectifier is subjected to widely varying loads and large changes in input line voltage. The design of the control is such that it can be used on either large or small rectifiers without any circuit changes.

Regulated Rectifier Basic Elements

The basic elements of a regulated rectifier (Figure 1) are a critically designed filter, a source of constant d-c potential, a high-gain d-c amplifier, thyratron-controlled saturating reactors and the selenium-oxide-rectifier disks with their associated transformers. In brief, the operation of these sections is as follows: The d-c voltage output of the selenium rectifier is passed through a filter to eliminate the a-c ripple and then compared against a constant d-c potential. This difference between the filtered rectifier voltage and a constant potential is applied to the grid of a high transconductance tube used as a d-c amplifier. Such circuiting gives relatively large d-c voltage changes from the amplifier for small changes in rectifier voltage. These changes in amplified direct current are used to form the basis for a d-c phase-shifting network that controls the grids of a pair of thyratrons. The regulated output of the thyratrons is circulated through the secondary windings (connected in series with proper phase relationship so that reflected primary voltages cancel)

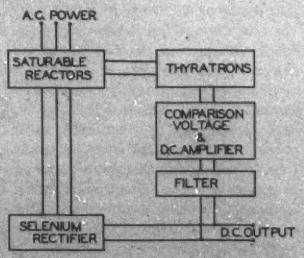

Figure 1. Block diagram

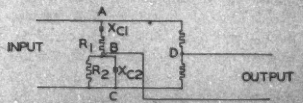

Figure 2. Filter circuit to eliminate ripple from d-c output voltage before comparing against fixed voltage

f = fundamental ripple frequency

$$X_{C1} = \frac{1}{2\pi f C_1}$$

$$X_{C2} = \frac{1}{2\pi f C_2}$$

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of saturating reactors that are in turn in series with the primary windings of the rectifier power transformers. The components of the control are sequenced so that if, for example, an increase in load were to tend to lower the rectifier voltage, the decrease in voltage would be amplified and used to shift the thyratron grids forward to cause greater saturating current to flow through the reactors decreasing the drop across the reactors and increasing the voltage across the power transformer.

Filter Design

One of the greatest single problems encountered in the development of the successful circuit was that of a suitable filter for the potential taken from the rectifier output to actuate the control. Because of the necessity for using a comparison voltage and an amplifier, even the small a-c ripple present in the output of a three-phase selenium rectifier is amplified enough, if applied directly without filtering, to render the phase-shifting circuit of the thyratron completely inoperative. The commonly used reactor-capacitor filters were found to be impractical. Their extremely high time constants make it impossible for such filters to follow rectifier voltage variations very closely with the result that they cause the rectifier to hunt and oscillate. The filter required therefore was one with a very high a-c attenuation factor, practically no d-c attenuation, and an extremely low time constant. The answer was found to lie in a variation of the Wien bridge (Figure 2).

By proper selection of constants it is possible to have the a-c voltage from B to C equal in phase and magnitude to the a-c voltage from D to C. As these vectors then subtract, the a-c potential from B to D equals zero. Resistance R_3 across X_{C_1} acts to keep the d-c potential between B and C equal to zero. To hold the d-c attenuation at a minimum, X_{C_1} should be very small as compared to X_{C_3}; however, any decrease in X_{C_1} will result in an increase in the time constant of the filter. The constants of the filter may be calculated and curves computed for the lowest possible time constant by use of the following equations:

$$Z_{BC}=\frac{R_3X_{C_3}^2}{R_3^2+X_{C_3}^2}-j\frac{X_{C_3}R_3^2}{R_3^2+X_{C_3}^2}=R_{BC}-jX_{BC}$$

As the voltage across BC must be in phase with the voltage across AB,

$$R_1/R_{BC}=X_{C_1}/X_{BC}$$

The time constant of the filter is a function of C_1 and the resistance in series with it, that is, R_1+R_3:

$$\text{Time constant} \propto C_1(R_1+R_3)$$

For example, if in a three-phase full-wave rectifier whose fundamental ripple frequency is 360 cycles, $R_1=100$ ohms, X_{C_1} equals 100 ohms (4.4 microfarads), and R_3 equals 2,000 ohms, the d-c output of the filter will be approximately 91 per cent of its input. If the time constant were to be cut in half by changing X_{C_1} to 200 ohms (2.2 microfarad), the output of the filter would still be approximately 83 per cent of input.

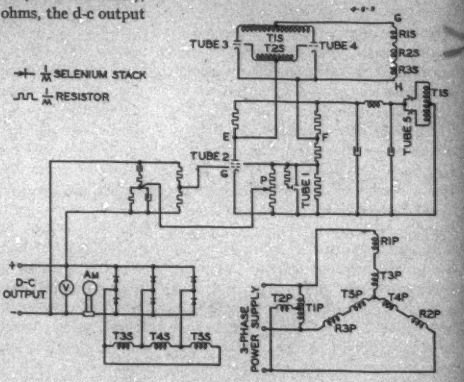

Figure 3. Simplified control circuit

T1P—Transformer 1 primary winding
T1S—Transformer 1 secondary winding
R1P—Saturable reactor 1 primary winding
R1S—Saturable reactor 1 secondary winding

Comparison Voltage and Amplifier

The output voltage of the filter is compared with a constant voltage obtained from potentiometer P (Figure 3), and the difference is applied to the grid of tube 2 for amplification. As we are taking the difference between two voltages, small changes in filter voltage mean relatively large percentage changes in the tube grid potential. For example, if the filtered voltage were 25 volts and the constant comparison voltage 24 the difference or applied grid voltage would be one volt. Now if the filtered voltage increases four tenths of one per cent to 25.1 volts the grid voltage increases to 1.1 volts which, of course, is an increase of ten per cent. The variations in grid voltage of tube 2 cause it to act as a variable resistance. The changes in internal resistance of the tube will naturally cause changes in the voltage drop across the tube. These voltage changes are such as to tend to limit the voltage amplification obtained. However, beam power tubes or pentodes which are little affected by plate voltage give excellent results. By operating tube 2 with a low screen grid potential which is maintained constant and proper choice of load resistance it is possible to obtain d-c voltage amplification of 20 to 30 decibels with one tube.

The constant voltage used for comparison against the filtered potential can be obtained by several methods. Probably the simplest source can be found in gaseous regulator tubes. Such tubes are readily available and are produced today with excellent characteristics and long life. The regulator tube shown as tube 1 in Figure 3 supplies constant voltage for two purposes. As the screen current of tube 2 will tend to vary with changes in grid voltages, additional amplification and stability is obtained by using the constant drop across tube 1 for the screen grid bias of tube 2. A potentiometer P bridged across the regulator tube provides the constant voltage to be compared against the filtered output. The potentiometer is the means by which the control is set for any desired rectifier output potential.

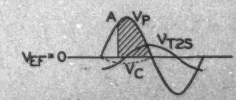

Figure 4A. Phase relations of thyratrons with d-c component of grid voltage equal to zero

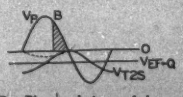

Figure 4B. Phase relations of thyratrons with d-c component of grid voltage equal to negative quantity

V_p—Thyratron anode voltage
V_{T2S}—A-c component of thyratron grid voltage
V_{EF}—D-c component of thyratron grid voltage
VC—Critical thyratron firing voltage

Phase-Shifting Network

As the internal resistance of tube 2 can be varied from extremely high values to very low ones, the potential across EF (V_{EF}) can be swung from positive through zero to negative. V_{EF} combined with the a-c output of transformer T_3 forms a d-c phase-shifting network that controls the grids and consequently the output of the thyratron, tubes 3 and 4. The voltage across the secondary winding of transformer 2 has been shifted 90 degrees with respect to the secondary winding of the plate transformer of the thyratrons,

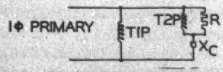

Figure 5. Single-phase network to obtain voltages shifted 90 degrees with respect to reference voltage

X_C is much greater than R

transformer 1. If V_P is the plate voltage of one of the thyratrons, and V_{TRS} is the grid voltage, Figure 4A shows that with $V_{EF}=0$ the grid-voltage curve intersects the critical grid curve at the point A where the tube fires and conducts current until $V_P=0$. However, if V_{EF} is equal to a negative quantity, Figure 4B, the tube will not fire until point B and will conduct correspondingly less than when $V_{EF}=0$. When V_{EF} goes positive, the critical grid voltage is intersected sooner, and more current is passed. The 90-degree phase shift required for V_{TRS} may be obtained by two methods. For single-phase operation (Figure 5) the primary winding of transformer 2 is connected in parallel with a resistance and both the transformers and the resistance are in turn connected in series with a capacitor. By making the impedance of the capacitor considerably more than that of the resistor, the current through the circuit can be made leading by almost 90 degrees. If this holds, then the voltage drop across the resistor, and consequently $T2P$ will be shifted 90 degrees also. For three-phase operation the voltage shift between $T1$ and $T2$ is conveniently obtained by using the Scott connection for converting three-phase power to two-phase (Figure 6).

Saturating Circuit

Tube 3, tube 4, and transformer 1 form a controlled rectifier, the output of which is used to saturate the reactors $R1$, $R2$, and $R3$. The primary windings of these reactors are in series with the primary windings of the power transformers $T3$, $T4$, and $T5$. The secondary windings of the reactors are connected so that the a-c voltages induced from their primary windings are subtractive, and the a-c potential from G to H equals zero. The division of voltage across the primary windings of the reactors and transformers is a function of the reactance of the reactor, the secondary loading of the reactor, the reactance of the transformer, and the secondary loading of the transformer. The reactances of the elements are determined by their physical characteristics, namely, the number of primary turns and lengths, area, and composition of the magnetic path. The secondary loading of the transformer consists of the rectifier stacks and the rectified power load. The control of the entire unit is obtained from the secondary loading of the reactors, which is, of course, the d-c saturating current. Amazingly large amounts of power may be controlled over wide voltage ranges by comparatively small amounts of saturating power. For example, 1,500 watts of rectified direct current is being handled in a small installation by 50 watts of saturating power.

From the designer's standpoint the most difficult problem is that of determining reactor sizes to meet voltage specifications under no-load conditions. This is

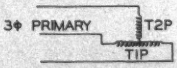

Figure 6. Three-phase network to obtain voltages shifted 90 degrees with respect to reference voltage

particularly true in cases where there are large fluctuations in line voltage or where wide-range voltage control is desired. Using the simplest type of series circuit shown in Figure 3, the no-load output voltage may be controlled from one-half to full voltage when the reactance of the reactor is equal to the reactance of the power transformer. Economically, it is not practical to try to obtain more than 50 per cent voltage control with the circuit shown. However, by proper circuiting it is possible to obtain zero to full voltage control without having to resort to the use of tap switches.

Performance

Although capable of extremely close control, the circuit as shown in Figure 3 is quite simple and uses relatively few

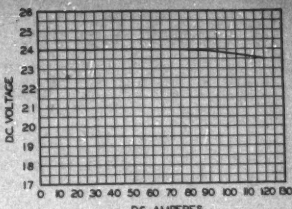

Figure 7. Performance curve of 100-ampere 24-volt electronically controlled selenium rectifier

vacuum tubes. Tubes were chosen with large cathode areas and are operated well below their rated output resulting in extremely long service life. Tube 5 is a rectifier tube supplying direct current for the amplifier tube 2. In controls for most industrial installations this tube would be replaced by a small selenium-oxide high-voltage bridge rectifier.

Figure 7 is a graph showing the voltage regulation underload of a controlled selenium rectifier which is being used for aircraft "transceiver" testing. The specifications call for a 100-ampere rectifier capable of having its output voltage varied smoothly from 20 volts to 30 volts and having very fine no-load to full-load voltage regulation at a normal operating point of 24 volts. The curve given was obtained with a primary power supply that had a five per cent to ten per cent voltage drop at full load. While a slightly drooping voltage characteristic is usually desired, the circuit may be changed so that the rectifier exhibits either a constantly rising voltage or else a voltage characteristic similar to that of a compound generator. One very satisfactory method of obtaining an output voltage that is a function of the output current is that of inserting a current transformer in the a-c primary power supply of the rectifier. The output of the current transformer is then rectified, filtered, and fed with proper polarity into the control circuit between the Wien bridge filter output and the comparison voltage.

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Electric Circuits and the Magnetic Compass

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Synopsis: This paper will endeavor to show the deviations in the airplane magnetic compass caused by electromagnetic effects from the ship's wiring and will suggest some means that can be used to correct them.

GLOBAL warfare has extended the field of operations of aircraft beyond radio beams, landmarks, highways, and beacon lights, and, hence, has made the magnetic compass of paramount importance. Because of steel structures, armor plate, and single-wire electric circuits which carry increasingly larger currents, the magnetic disturbances at the conventional compass location have increased to such an extent that several remote indicating types of compasses have had to be developed.

The marked trend in the use of remote indicating types of compasses has created a shortage in these instruments. One of the purposes of this paper is to point out some of the problems created in the design of the air frame that can be solved by certain design techniques and the application of basic electromagnetic principles, thereby restoring the usefulness of direct-reading compasses and improving the accuracy of the remote indicating types. The scope of this paper will be limited to electromagnetic disturbances since the subject of ferromagnetism involving soft-iron effects, residual magnetism and its control in design and manufacturing processes, and other allied problems is too far-reaching to be treated other than in a separate paper. It can be noted that highly satisfactory results have been attained at Lockheed-Vega in the control of the ferromagnetic properties of air frames, both through design and demagnetizing processes during manufacture.

Aircraft electric systems conventionally utilize d-c generators, motors, and storage batteries. Certain limited applications of alternating current are found wherein 400-cycle inverters are utilized to supply small quantities of power for autosyn and similar transmitters, as well as for certain radio applications. However, the d-c supply and field winding of these inverters often cause noticeable magnetic disturbances. Furthermore, as a weight-saving measure, the air frame has been used as a ground return, leaving the electromagnetic field surrounding the single "hot wire" with little, if any, neutralizing field from a parallel ground-return conductor. Until the air frame is fitted with sources of alternating current to the exclusion of direct current, this problem must be faced by the electrical designer in his work on air frame electric systems and equipment.

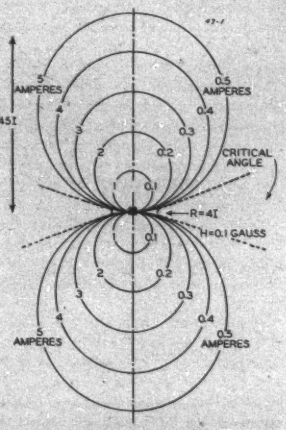

Figure 1. Horizontal wire-placement pattern for $H=0.1$ gauss. $D=1$ degree

The magnetic field in which the compass functions is extremely weak in comparison with the electromagnetic fields involved in power applications. The directive force utilized by the compass is the horizontal component of the earth's field, and this varies greatly over the surface of the earth, being zero at the magnetic poles and increasing to a maximum of approximately 0.40 gauss at the magnetic equator. When it is pointed out that the horizontal component of the earth's field along the North Atlantic ferry route varies between 0.15 and 0.10 gauss, it becomes apparent that a rather weak field surrounding a single-wire conductor in an air frame can cause deviations of a serious nature. Even in modern combat aircraft the remote indicating transmitter, located as favorably as possible, is subject to serious errors from this source. Since space limitations in aircraft dictate compass locations, and since the electric conductors must be located within the fuselage and wing surfaces, some serious problems arise that must be solved by ingenious electrical design.

The accepted practice in treating magnetic-compass problems is to resolve the magnetic field in question into two components: the horizontal component, which produces a directive force on the compass, and the vertical component, which has no directive force under normal conditions. Since the directive force is confined to the horizontal component of the magnetic field at the compass location, it will be affected only by the horizontal component of the magnetic field produced by any electric circuit. Any electric circuit may be separated into finite sections, and, if well-known electromagnetic formulas are used, the field at the compass location can be calculated for each section. These fields combined vectorially will give the components of the electromagnetic field caused by the electric circuit. Of course, it is the resultant horizontal component which directs the compass, and this will vary, not only with the intensity of the earth's field and the current flowing in

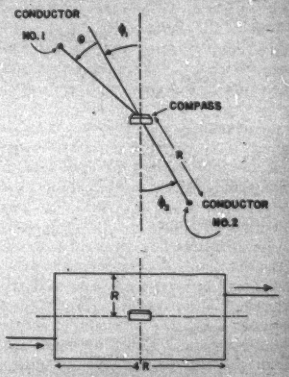

Figure 2. An illustration of angular asymmetry in split-wire neutralization

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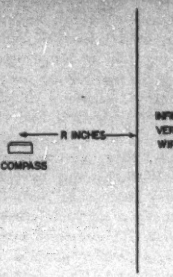
each electric circuit, but also will change with each heading of the aircraft.

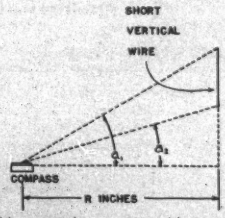
This deviation cannot be corrected by means of the regular compass compensator, and to allow for it in navigation would require a book full of deviation cards; consequently, these effects must be reduced to a certain allowable maximum. For example, in Southern California, where the horizontal component of the earth's field is 0.26 gauss, a certain current causes a deviation equal to plus two degrees, whereas the same current causes plus four degrees deviation in more northerly magnetic latitudes, and if the current increases the deviation will increase still further.

Present Air Force standards, as to deviation tolerances, are based on a horizontal component of the earth's field of 0.18 gauss, and a vertical component of 0.54 gauss, but, with aircraft operation increasing in northerly latitudes and transpolar air transportation a near actuality, the electrical designer can well anticipate a narrowing of the tolerance limits for compass deviations. Table I sets forth

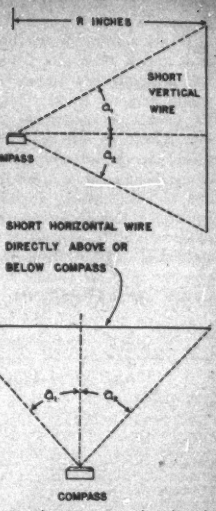


(a). Maximum deviation when wire is north or south of compass. Correct to ten per cent when D is less than 30 degrees. $D = 45\ l/R$ degrees

(b). No vertical component. Maximum $D = 22.5\ (l/R)\ (\sin a_1 + \sin a_2)$ degrees



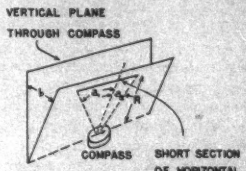
(c). No vertical component. Maximum $D = 22.5\ (l/R)\ (\sin a_1 - \sin a_2)$ degrees



(d). Maximum when wire is north and south. No vertical component. $D = 22.5\ (l/R)\ (\sin a_1 + \sin a_2)$ degrees

Table I. Calculated Distances, *R*, of Compass From Long Straight Conductor to Give Compass Deviation, *D*, of One Degree. Earth's Horizontal Magnetic Field in Gauss = *H*

Current		Distance for Deflection of One Degree					
		H = 0.1		H = 0.180		H = 0.264	
Ampere	Abampere	Centimeters	Inches	Centimeters	Inches	Centimeters	Inches
0.1	0.01	11.4	4.5	6.34	2.5	4.32	1.7
0.2	0.02	22.8	9.0	12.68	5.0	8.64	3.4
0.3	0.03	34.2	13.5	19.0	7.5	12.9	5.1
0.4	0.04	45.6	18.0	25.4	10.0	17.3	6.8
0.5	0.05	57.0	22.5	31.7	12.5	21.6	8.5
1.0	0.1	114	45.0	63.4	25.0	43.2	17.0
2.0	0.2	228	90.0	126.8	50.0	86.4	34.0
3.0	0.3	342	135.0	190.0	75.0	129.0	51.0
4.0	0.4	456	180.0	254.0	100.0	173.0	68.0
5.0	0.5	570	225.0	317.0	125.0	216.0	85.0
10.0	1.0	1,140	450	634	250	432	170
20.0	2.0	2,280	900	1,268	500	864	340
30.0	3.0	3,420	1,350	1,900	750	1,290	510
40.0	4.0	4,560	1,800	2,540	1,000	1,730	680
50.0	5.0	5,700	2,250	3,170	1,250	2,160	850



(e). Maximum when wire is north and south. $D = 22.5\ (l/R)\ (\sin a_1 + \sin a_2) \cos b$ degrees. Vertical field: $V = (l/25R)\ (\sin a_1 + \sin a_2) \times \sin b$ gauss

Figure 3. Compass deviations caused by straight conductors. $H = 0.1$ gauss

the calculated distances of a long straight horizontal conductor in a vertical plane above or below a compass location at which a deviation of one degree will be created by the currents designated for the three values of the earth's horizontal components shown.

The notable changes in these distances caused by weaker horizontal components of the earth's field and increasing currents are of serious importance. A useful family of curves, shown in Figure 1, can be plotted by drawing circles with their centers on a vertical line through the compass location, tangent to the compass location with diameters equal to these distances. If a long horizontal north–south conductor is placed directly above or below the compass at a distance equal in inches to 45 times the current in amperes, then the deviation will be plus or minus one degree when the horizontal component of the earth's field is 0.10 gauss. This conductor can be placed anywhere on the circle with the same horizontal component at the compass if the current and direction remain the same. Where these curves approach the compass location, positioning of the conductor becomes quite critical to slight vertical displacements, and allowance should be made for possible changes in the position of either the compass or the conductor.

Figure 1 suggests a neutralizing technique where the removal of the conductor to a safe distance or the installation of a return ground wire is not desirable. The technique employs a division of the circuit between two parallel conductors. Each one is placed on its circle, one above and one below the compass location. By extending the split circuit a distance of four times the diameter of the circle used, 90 per cent of the disturbance will be neutralized. The use of this method will be confined to sections of the air frame which will give the necessary length and symmetry for properly aligning the conductors, such as in the fuselage, boom, or wing. Where space does not permit equal distances in each direction from the

compass location, the current can be split in proper portions by varying the wire cross section so that the conductors will fall on appropriate current circles. It should be noted further that, although the horizontal components of the two split conductors will be equal and opposite, the vertical components will not be equal and opposite unless the conductors are diametrically opposite. However, the vertical components can be added vectorially, and should the resultant exceed values to be discussed subsequently, an effort should be made to achieve complete symmetry.

ponent that occurs when the aircraft changes attitude from horizontal flight position, either by "roll" or by changes in angle of attack due to loading or other causes. For instance, consider a circuit which produces only a vertical field of 0.020 gauss at the compass location in flight attitude *A*. Now, let the flight attitude change to *B*, differing by five degrees from *A*. The former vertical field will now have a horizontal component equal to 0.00175 gauss which, over the North Atlantic, would produce a deviation of one degree. This vertical field of 0.020 gauss is produced at a horimated from electromagnetic formulas by taking the circuit in sections, but it is far more satisfactory to measure the disturbance with a magnetometer in a finished airplane. The principle reason for the unsatisfactory solution arrived at by the mathematical treatment alone is that the return circuit through the air frame is not uniform, but is distorted by joints in the skin, extrusions attached to the frame, openings, and even magnetic fields. However, a direct measurement is relatively easy to make by use of a good magnetometer. The airplane is placed in flight attitude on a north magnetic heading, and the magnetometer pickup element is placed in the compass location so oriented that it will measure a horizontal component of the earth's field along the axis of the ship. The circuit in question is then switched on and off, and the magnetometer readings are taken for both field strengths. The difference gives the magnitude of this axial component of the disturbing electromagnetic field. The magnetometer pickup element is next oriented horizontally crosswise of the ship, and the same procedure is repeated. The third observation is made with the axis of the magnetometer vertical, and from these three components it is quite easy to determine the direction and magnitude of the disturbing flux. A small series coil may then be arranged in the neighborhood of the compass so that the field produced by this coil will, at the compass location, be equal and opposite to that produced by the circuit causing the disturbance. The coil then should be installed, and the result should be checked on all three axes with the magnetometer.

From the foregoing it is evident that the electric circuits necessary to the operation of the airplane are the cause of many compass errors. It is further seen that these errors can be anticipated by calculation from the geometry of the ship's wiring, and that the wiring can be rearranged so that the errors will be reduced to a negligible quantity, or, where it is not possible to move the wiring, it may be possible to find a solution by using double conductors, or coaxial conductors, or even by dividing the circuit into symmetrical paths. It is further shown that it is possible to compensate for the disturbance caused by any given electric circuit by the use of a series compensating coil, precalculated and properly oriented, to cancel out all components of the disturbing flux at the compass location.

Table II. An Example of Angular Tolerances for Split-Wire Neutralization

Data: $R=36$ inches, $H=0.100$ gauss, $I=10$ amperes, $D=1$ degree

ϕ_1*	θ	
0 degrees	+24 degrees 25 minutes	−24 degrees 25 minutes
10 degrees	+16 degrees 27 minutes	−24 degrees 25 minutes
20 degrees	11 degrees 46 minutes	−24 degrees 25 minutes
30 degrees	9 degrees 3 minutes	−18 degrees 40 minutes
40 degrees	7 degrees 26 minutes	− 9 degrees 16 minutes
50 degrees	6 degrees 24 minutes	− 7 degrees 25 minutes
60 degrees	5 degrees 46 minutes	− 6 degrees 14 minutes
70 degrees	5 degrees 22 minutes	− 5 degrees 50 minutes
80 degrees	5 degrees 11 minutes	− 5 degrees 30 minutes
90 degrees	5 degrees 8 minutes	− 5 degrees 22 minutes

* ϕ_1 may be + or −, but, as ϕ_1 changes sign, θ values must also change sign. See Figure 2.

When it is impossible to arrange the two wires of the split-wire system in perfectly symmetrical positions, it is possible to allow relatively large amounts of asymmetry as to angle and still have a resultant field producing less than one-degree deviation of the compass. The angle of tolerance depends upon the distances, the current, and the position angle of the conductors, as shown in Figure 2. The tabulated values in Table II are obtained from the formula $B_2-B_1=0.072\ (I/R)\ [\cos\phi-\cos(\phi\pm\Theta)]$, where B_1 and B_2 are the horizontal fields at the compass of conductors 1 and 2. For example, Table II illustrates a 20-ampere conductor which has been split at a distance of $4R$ with each leg carrying ten amperes and R taken as 36 inches.

After the horizontal component has been considered, the vertical component should be examined. A current-carrying conductor can lie precisely in a horizontal plane passing through the compass, and no horizontal component will exist to cause deviation of the earth's field. However, a vertical component of considerable intensity can exist, which, if excessive, can cause the compass card to dip into the vertical field. More important, however, is the resultant horizontal component of the horizontal distance in inches equal to four times the current in amperes. That is to say, if 40 inches from a horizontal wire carries ten amperes, the field is 0.020 gauss. From the foregoing it would seem that a desirable compass-performance standard would be to limit the permissible deviation to one degree where the horizontal component of the earth's field is 0.10 gauss.

Figure 3 has been prepared to permit easy calculations where data are in inches, amperes, and degrees instead of centimeter-gram-second units. The formulas give the compass deviation D in degrees caused by straight conductors in various relationships to the compass location. All are based on a horizontal component of the earth's field of 0.10 gauss.

A complete compensation of any one circuit is possible by means of a compensating coil which carries the current equal or proportionate to the current in the disturbing circuit and is placed so that the magnetic field of this coil supplies a flux at the compass location which is exactly equal in magnitude and opposite in direction to the combined disturbance at that location of all the rest of the circuit.

The disturbance which will be caused by any single-wire circuit can be approxi-

Asymmetrical Loading of Three-Phase Three-Winding Transformer Banks

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Synopsis: It is accepted USSR practice to carry three-phase industrial load and single-phase traction load on a single three-phase three-winding transformer. For a given combination of loads it is necessary to determine the proper capacity relationships of the three windings.

This paper presents an analysis of the problem by the methods of symmetrical components. The data obtained from this analysis were used in setting up the standards for selection of transformer size for combined three-phase industrial and single-phase traction loading.

THE problem of unbalanced loading of three-phase transformer banks is of practical importance both in industrial installations where single-phase equipment, such as welders, is supplied and in railway installations where single-phase traction loads are fed from industrial three-phase banks. The present investigation deals only with the case of single-phase traction loading.

Since combination of symmetrical three-phase industrial load, and single-phase traction loading on three-phase transformer banks is no different from other types of asymmetrical loading, the solution to the one problem may be applied to all cases of asymmetrical loading practice.

The condition studied is that of the three-phase bank of three-winding single-phase transformers loaded asymmetrically. The transformer winding connections would be as follows:

1. The primary winding would be wye-connected with the neutral grounded.
2. The secondary winding would be delta-connected for symmetrical three-phase loading.
3. The tertiary winding would be wye-connected with the neutral ungrounded for asymmetrical loading.

The most frequent type of loading for traction circuits is the two-phase asymmetrical loading such as is shown in Figure 1.

In the solution of the problem of the capacity relationships of the separate windings, it is necessary to determine current distribution in the windings and effective voltage. The effect of magnetizing current is neglected.

The solution is for the equivalent star circuit as shown in Figure 2. The effective impedances of the separate branches of the circuit corresponding to the impedances of the transformer phase windings are

$$Z' = \frac{Z_{12}+Z_{31}-Z_{23}}{2} \quad (1)$$

$$Z'' = \frac{Z_{23}+Z_{12}-Z_{31}}{2} \quad (2)$$

$$Z''' = \frac{Z_{31}+Z_{23}-Z_{12}}{2} \quad (3)$$

where Z', Z'', and Z''' represent the effective impedances of the branches of the equivalent circuit as shown in Figure 2, and Z_{12}, Z_{23}, and Z_{31}, represent the leakage impedances between windings as obtained from short-circuit tests.

The current distribution may be determined by the application of symmetrical components. In so doing, it is necessary to consider the internal impedances of the system. Refer again to the circuit of Figure 1, and if the neutral remains ungrounded, the asymmetrical loading has no zero-sequence current components, that is, $I_0=0$.

The current and voltage relationships for the circuit may be represented by the positive- and negative-sequence components

$$I_a = I_1 + I_2 \quad (4)$$

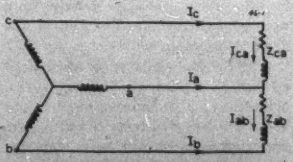

Figure 1. Method of connection of asymmetrical traction load to the star-connected secondary of a three-winding transformer

$$I_b = a^2 I_1 + a I_2 \quad (5)$$

$$I_c = a I_1 + a^2 I_2 \quad (6)$$

and

$$\dot{V}_a = \dot{V}_1 + \dot{V}_2 \quad (7)$$

$$\dot{V}_b = a^2 \dot{V}_1 + a \dot{V}_2 \quad (8)$$

$$\dot{V}_c = a \dot{V}_1 + a^2 \dot{V}_2 \quad (9)$$

where $\dot{V}_1$ and $\dot{V}_2$ are the positive- and negative-sequence components of the voltage drop across the impedance of the external asymmetrical loads. Considering equations 4 through 9, equations for the circuits based on Kirchhoff's second law may be written as

$$I_a = I_1 + I_2 = \frac{\dot{V}_1(1-a^2)+\dot{V}_2(1-a)}{Z_{ab}} + \frac{\dot{V}_1(1-a)+\dot{V}_2(1-a^2)}{Z_{ac}} \quad (10)$$

$$I_b = a^2 I_1 + a I_2 = \frac{\dot{V}_1(a^2-1)+\dot{V}_2(a-1)}{Z_{ab}} \quad (11)$$

$$I_c = a I_1 + a^2 I_2 = \frac{\dot{V}_1(a-1)+\dot{V}_2(a^2-1)}{Z_{ac}} \quad (12)$$

These equations, including the unknowns, I_1, I_2, $\dot{V}_1$, and $\dot{V}_2$, are not sufficient to complete the solution of the problem. To obtain the necessary additional conditions, it is necessary to determine the internal impedance components Z_0, Z_1, and Z_2 of the transformer windings.

Since it has been assumed that the applied primary potential is symmetrical, its zero- and negative-sequence components will be equal to zero. It follows that the effective electromotive force in the system of zero sequence and negative sequence will be zero, also, while in the positive-sequence system the electromotive force will be V_ϕ. These relationships may be expressed as

$$0 = I_0 Z_0 + \dot{V}_0 \quad (13)$$

$$\dot{V}_\phi = I_1 Z_1 + \dot{V}_1 \quad (14)$$

$$0 = I_2 Z_2 + \dot{V}_2 \quad (15)$$

to show the relationship of the effective electromotive forces of any system and the voltage drops in the internal and external impedances of the system.

Solution of the equations 10 to 15, inclusive, is in the form of

$$I_1 = \frac{\dot{V}_\phi(Z_{ab}+Z_{ac}+3Z_2)}{Z_{ab}Z_{ac}+(Z_1+Z_2)(Z_{ab}+Z_{ac})+3Z_1Z_2} \quad (16)$$

and

$$I_2 = \frac{-\dot{V}_\phi\left(Z_{ab}a+\frac{Z_{ac}}{a}\right)}{Z_{ab}Z_{ac}+(Z_1+Z_2)(Z_{ab}+Z_{ac})+3Z_1Z_2} \quad (17)$$

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where

I_1 = positive-sequence current

I_2 = negative-sequence current

Z_1 = positive-sequence impedance of the whole equivalent circuit

Z_2 = negative-sequence impedance of the whole equivalent circuit

Z_{ab} and Z_{ac} = impedance of the asymmetrical loads with reference to the primary winding as obtained from

$$Z_{ab} = \frac{V^2}{P_{ab}} (\cos \theta + j \sin \theta) \qquad (18)$$

where

V = primary interphase voltage in kilovolts

P_{ab} = capacity of the corresponding branch of the circuit, in megavolt-amperes

$\cos \theta$ = power factor of the asymmetrical load

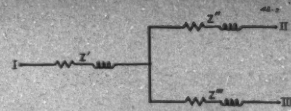

Figure 2. Equivalent star circuit of a three-winding transformer

By use of the principle of superposition, electromotive forces are assumed to be applied at this point, feeding the system by the positive- and negative-sequence currents. The effective negative-sequence voltage at the primary-winding terminals may be considered to be zero.

To establish the true current distribution in the transformer windings, it is necessary first to establish the distribution of currents of the positive I_1, and the negative I_2 sequences among the paths of the corresponding system. Such distribution is, of course, inversely proportional to the impedances of the parallel paths. Such current in each path must be added to the normal symmetrical current, I_p, of that path.

Then the current of the most-loaded phase of the primary winding will be

$$I_a' = I_p + I_1 + I_2 \qquad (21)$$

In approximating the current components I_1 and I_2 of the asymmetrical load, only the normal no-load phase voltage, V_ϕ, at the terminals of the star-connected winding is considered. The corresponding phase voltage at the primary-winding terminals will be $\dot{V}_\phi + \dot{I}_p Z'$ where $\dot{I}_p Z'$ is the primary-winding voltage drop caused by the symmetrical load on the delta-connected secondary.

After the application of the asymmetrical load, the tertiary-winding voltage will be less than V_ϕ. It follows that conditions under which the currents I_1 and I_2 were first approximated will have been disturbed. In order that the terminal voltage V_ϕ be maintained constant with load, it is necessary to increase the primary-winding voltage to $K(\dot{V}_\phi + \dot{I}_p Z')$ where K is a correction factor greater than one, based on the voltage drop caused by the asymmetrical load.

The voltage under asymmetrical-load conditions at the terminal of the tertiary winding, point III of the equivalent system of Figure 3, may be obtained by application of the methods of symmetrical components to the equivalent system. The positive-sequence voltage-drop component, starting from zero potential at point I in Figure 3, is $(-\dot{I}_1' Z' - \dot{I}_1 Z''')$ where I' is the component of the positive-sequence current in the path Z'. Similarly, the negative-sequence voltage drop at the same point is $(-\dot{I}_2' Z' - \dot{I}_2 Z''')$ where I_2' is the negative-sequence current in the path Z'.

It follows that, in Figure 3

$$\dot{V}_1 = \dot{V}_\phi - \dot{I}_1' Z' - \dot{I}_1 Z''' \qquad (22)$$

and

$$\dot{V}_2 = -\dot{I}_2' Z' - \dot{I}_2 Z''' \qquad (23)$$

where $\dot{V}_1$ and $\dot{V}_2$ are positive- and negative-sequence voltages, respectively, at point III.

Table I. Load Distribution and Capacity Relationship for the Most-Loaded Phase of a Three-Winding Transformer With Asymmetrical Loading

Case Number	Asymmetrical Load Megavolt-Amperes P_{ab}	Asymmetrical Load Megavolt-Amperes P_{ac}	Symmetrical Load Megavolt-Amperes	Ratio of Asymmetrical Load to Total Load Per Cent	Winding Loads of the Transformer for the Most-Loaded Phase "a": Tertiary (Single-Phase Traction) Megavolt-Amperes	Tertiary (Single-Phase Traction) Per Cent of Primary	Secondary (Three-Phase Regional) Megavolt-Amperes	Estimated Primary Megavolt-Amperes	Winding Capacity Relationship According to Standard OCT 2,524 (Per Cent): Tertiary	Secondary	Primary
1	9.9	8.6	4.9	79	10.7	99	1.85	10.80	100	67	100
2	9.9	8.6	9.3	67	10.7	82	3.10	13.00	67	67	100
3	9.9	8.6	15.0	35	10.7	75	5.00	14.35	67	67	100
4	9.9	8.6	22.0	46	10.7	63	7.35	16.85	67	67	100
5	8.8	4.6	5.9	70	7.8	91	1.96	8.45	67	67	100
6	8.8	4.6	13.4	50	7.8	70	4.57	11.02	67	67	100

The internal, or applied negative-sequence impedance of the system includes also the impedance of the symmetrical load taken for the corresponding branch of the circuit

$$Z_p = \frac{V^2}{P_p} (\cos \beta + j \sin \beta) \qquad (19)$$

where $\cos \beta$ is the power factor of the symmetrical load.

Since the positive- and negative-sequence impedances of the transformer are equal, Z_1 and Z_2, the impedances of the whole equivalent circuit will differ only by the difference between the positive and negative sequence impedances of the symmetrical load in the secondary delta winding.

To bring the total impedance in the positive- and negative-sequence system up to the point at which the asymmetrical load is to be applied, it is necessary to include the impedance of the parallel paths, both primary and secondary. This is expressed by

$$Z_1 = \frac{Z'(Z_p + Z'')}{Z' + Z_p + Z''} + Z''' \qquad (20)$$

referred to in Figure 3.

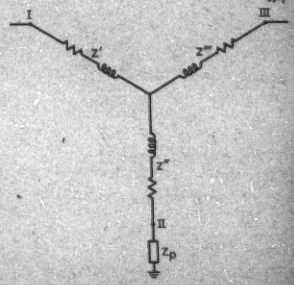

Figure 3. Equivalent star circuit of a three-winding transformer showing balanced load on the delta-connected secondary

The actual phase voltage will be

$$\dot{V}_a = \dot{V}_1 + \dot{V}_2 \qquad (24)$$

$$\dot{V}_b = a^2 \dot{V}_1 + a \dot{V}_2 \qquad (25)$$

$$\dot{V}_c = a \dot{V}_1 + a^2 \dot{V}_2 \qquad (26)$$

and since

$$a^2 = -0.5 - j\,0.866$$

and

$$a = -0.5 + j\,0.866$$

equations 25 and 26 may be rewritten as

$$\dot{V}_b = -0.5(\dot{V}_1 + \dot{V}_2) + j\,0.866(\dot{V}_1 - \dot{V}_2) \qquad (27)$$

$$\dot{V}_c = -0.5(\dot{V}_1 + \dot{V}_2) - j\,0.866(\dot{V}_1 - \dot{V}_2) \qquad (28)$$

From these equations the interphase voltages may be calculated to be

$$\dot{V}_{ab}=\dot{V}_a-\dot{V}_b=1.5(\dot{V}_1+\dot{V}_2)+j0.866(\dot{V}_1-\dot{V}_2) \quad (29)$$

$$\dot{V}_{ca}=\dot{V}_c-\dot{V}_a=-1.5(\dot{V}_1+\dot{V}_2)+j0.866(\dot{V}_1-\dot{V}_2) \quad (30)$$

$$\dot{V}_{bc}=\dot{V}_b-\dot{V}_c=j1.732(\dot{V}_1-\dot{V}_2) \quad (31)$$

In the foregoing discussion a factor K was presented to correct for the difference between load and no-load conditions of difference between terminal voltage at point III in Figure 3 and primary voltage

Table II. Relationship of Phase Load to Phase-Winding Load

Asymmetric Load in Per Cent of Total Load	Phase-Winding Load in Per Cent of Phase Load
80	100
70	91
67	82
55	75
50	70
46	63

at point I. The value of K may now be obtained as the arithmetic mean value of the calculated voltage ratios for the two loaded phases. If

$$K'=\frac{\sqrt{3}V_\phi}{V_{ab}} \quad (32)$$

and

$$K''=\frac{\sqrt{3}V_\phi}{V_{ac}} \quad (33)$$

then

$$K=\frac{K'+K''}{2} \quad (34)$$

and

$$\dot{V}_a'=K(\dot{V}_\phi+\dot{I}_\phi'Z') \quad (35)$$

where $\dot{V}_a'$ is the primary voltage at point I in Figure 3.

Conclusion

The foregoing analysis of the loading of asymmetrical three-phase three-winding transformer banks has been verified by laboratory observations of current distribution and effective voltages under such conditions. A thorough practical investigation has confirmed fully the correctness of the conclusions arrived at mathematically.

It appears to be reasonable that equations established in this manner may be used in estimating the required capacity of the most-loaded phase of three-phase three-winding transformers subjected to such loading.

The results of calculations made for different combinations of symmetrical regional and asymmetrical traction loads are given in Table I.

In expressing the A-phase capacity in kilovolt-amperes, the transformer primary-winding power for this phase is represented by

$$P_a'=\dot{I}_a'V_a' \quad (36)$$

The predetermined transformer loads are represented in Table I. As a first approximation, it is assumed that the phase load on the traction winding is the sum of the two path loads $P_{ab}/\sqrt{3}+P_{ac}/\sqrt{3}$ which fall on this phase, as shown in Figure 1. Actually this approximation will be higher than the measured winding load.

The symmetrical load of the delta-connected secondary is assumed to be the same in all three phases.

The results of the foregoing analysis disclose a characteristic feature of load distribution in three-phase three-winding transformers under the conditions of asymmetrical loading. As shown in Table I, the A-phase primary winding does not carry the sum of the secondary- and tertiary-winding loads of this phase as it would in the case of symmetrical loading. A part of the load of the most-loaded A phase will be carried by the other less-loaded phases.

The portion of the total phase load carried by the phase winding varies with the relationship between asymmetrical load and total load. The relationship for the most-loaded phase is shown in Table II.

According to Standard for Transformers of the Union of Soviet Socialist Republics, *OCT* 2,524, the size of the single-phase transformers of the three-phase bank will be determined by the relationships 100:67:100 and 100:67:67 corresponding to winding voltages of 110 kv, 35 kv, and 11 kv, respectively. These relationships are used for practical application to this type of loading.

Electrification of Large Open-Pit Copper Mines

L. W. BIRCH
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Synopsis: The transportation problem of a large strip mine involves the loading, hauling, and dumping of both ore and waste. These materials are loaded with large electric shovels operating on benches along the slope of a hill or pit. The ore is transported over main-line tracks to the reduction plant, while the waste is hauled to suitable dumps. All main-line tracks are permanent and are equipped with permanent overhead distribution systems (Figure 1). All bench and dump tracks are portable and are equipped with portable overhead distribution systems.

Sixty per cent of the world's copper is now obtained by open-pit mining of low-grade ore. Electrification of haulageways for open-pit mining is keeping pace with the expansion and is modernizing the transportation of huge tonnages. Huge capacities necessitating heavy cars and heavy grades demanding short-period overloads have been responsible for the selection of the electric locomotive for motive power. From the standpoint of locomotive capacity, rail size, dump-car capacity, and density of traffic, most open-pit electrifications compare in size with our large steam-road installations and hold an important place in the field of heavy traction (Figure 2).

In addition to describing the haulage problem of large open-pit copper mines, this paper discusses the design of permanent and portable distribution systems.

OPEN-pit mining, commonly called quarrying, is familiar to everybody and can scarcely be termed a new process, since materials for the many historic structures of Egypt, Rome, and China were obtained by "pit quarrying." However, open-pit mining, as applied to modern large tonnage operations, is a highly developed and highly mechanized process for recovering minerals from large ore bodies and is dependent on heavy haulage facilities, usually electrified.

Our domestic mine output of copper, estimated in excess of 1,000,000 tons for 1942 and representing 15 per cent increase over 1940, has been possible, chiefly because of the development of open-pit mining methods. Because of high costs, underground mining is greatly limited to high-grade ores and to comparatively low tonnage. Deeper shafts and greater penetration increase the underground haulage costs, since access to the ore body must be made from the surface, and the shafts cannot be moved at will. Then, too, the depletion of easily available deposits of high-grade ore has influenced the expansion of open-pit mining. Therefore, either the mining of low-grade ores or the removal of large deposits involving considerable overburden and waste rock is almost exclusively a stripping operation. Strip mining has not only given the operator an economical plant but has put an end to an important waste in his plant—the waste of natural resources.

The Utah Copper Company is credited with originating the recovery of copper from low-grade ore on a large tonnage basis. Other companies, including Nevada Consolidated, Ray Consolidated, and Chino (Nevada Consolidated in New Mexico), furthered the development and commercialization of the process. South America and Africa are also large producers of copper from low-grade ores, the Katanga project in the Belgian Congo representing the most recent undertaking. At the present time 60 per cent of the world's copper is secured from mammoth strip operations in low-grade copper.

It has been only a short time since the bulk of our domestic copper was mined in Montana and Michigan, both states operating immense underground workings. Today the open pit mines in Arizona, Nevada, New Mexico, and Utah are producing large quantities of copper from low-grade ores, and, as a consequence, Montana and Michigan are third and sixth, respectively, on the list of copper-producing states. Some detailed data for 1941 may be found in Table I.

Table I. Copper-Producing States

State	Tons
Arizona	326,000
Utah	267,000
Montana	128,000
Nevada	79,000
New Mexico	73,000
Michigan	46,000
Other states	38,000

It is interesting to note from Table I that Arizona and Utah produced 62 per cent of the domestic copper in 1941. Statistics also show that these states produced 18 per cent of the world copper in 1939, the last year for which accurate figures were available. Perhaps a description of one of the most recent open-pit undertakings will acquaint you with modern large-scale stripping operations, and also with the importance of adequate transportation facilities for handling the thousands of tons of ore and waste. This operation is the Morenci mine of the Phelps Dodge Corporation in Arizona.

Typical Example of Open-Pit Mining

Early mining operations at Morenci were underground. Evidence of this early mining can be seen in several locations in the new pit, where stripping has broken through the old workings. Only the high-grade deposits attracted the first miner. Operations were restricted to the secondary enriched areas and to replacement deposits occurring in sedimentary rocks. The copper content of these ores was adequate to warrant the cost of mining, transporting, milling, and smelting. Following the exhaustion of these ores, mining operations were transferred to the monzonite porphyry, where rich ore was again found in fissures also as disseminations in the porphyry. Later, mining was extended to the lower-grade disseminated ores where operation by the block-caving method continued for many years.

All of this early mining contributed to the development of the new Morenci pit. Commercial mining uncovered the large deposits of low-grade porphyry ore. Extensive exploration work with churn drills, diamond drills, and continued underground mining fixed the pit limits and determined the size and quality of the huge ore body.

The low-grade ore of the Morenci pit consists chiefly of chalcocite disseminated in monzonite porphyry. Chalcocite, a sulphide ore, occurs in many of the western open-pit copper mines, such as the Bingham mine of the Utah Copper Company, the Phelps Dodge Corporation Ajo pit, and the open pits of the Nevada Consolidated Copper Corporation at Santa Rita, N. Mex., and McGill, Nevada. Rarely does the copper content of these large open-pit mines average more than one per cent. At Morenci, the ore averages 1.06 per cent copper.

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Economy dictates the amount of waste that can be removed in any stripping area (Figure 3). The cost of loading, hauling, and dumping must be maintained within a definite figure. Too much waste removal, long hauls, and distant waste dumps increase mining costs. For all stripping operations the amount of waste that can be removed economically bears a definite relationship to the amount of ore recovered. For coal stripping, the miner's rule of thumb is one foot of overburden for one inch of coal. In low-grade high-tonnage copper-stripping operations the ratio is one ton of waste for one ton of ore. Therefore, the hauling of ore is one half of the problem, and the hauling of wastes is the other half.

At Morenci the waste includes an overburden, or capping, which has a maximum thickness of 500 feet and an average thickness of 216 feet above the ore body. Preliminary stripping required the removal of 50,000,000 tons of material, mostly waste, in order to assure the initial removal of 25,000 tons of ore daily. All material not used for truck highways was hauled to dumps or to the railroad right of way for fills. The preliminary digging in was accomplished with 18 large trucks capable of handling $22\frac{1}{2}$ yards of material. Many miles of excellent roadway were constructed for truck haulage, since the loaded truck weight was 65 tons, and grades were as high as ten per cent.

The removal of ore at Morenci is accomplished by the establishment of a series of benches, the number depending on production requirements (Figure 4). Since each bench represents a separate or independent mining operation, this bench method of open-pit mining is usually the most economical. The benches are equivalent to a stairway, each tread representing the floor where the shovels operate to load dump cars, each riser representing the working face where the ore is broken away. The height of the bench is determined by the shovel equipment, limitations to drilling, and the nature of the material. In this case the height of each bench is 50 feet, and its width, being determined by the requirements for shovel operation and haulage facilities, is 100 feet.

The Haulage Problem

Following the establishment of benches, the ore and waste rock are broken away from the face by blasting, the length of the blasted section often extending a distance of 1,000 feet (Figure 5). For loading purposes, secondary blasting is usually necessary for further fragmentation of the larger rocks. Additional blasting is also necessary for removing the toe where the face and floor intersect. Removal of the toe provides a vertical bank and reduces overshooting and undershooting, thus permitting the burden carried by each drill hole to be estimated more accurately. The preparation of ore, therefore, becomes an important factor in the haulage problem. The track and overhead distribution system must be planned either for quick removal or for resisting a certain amount of flying rock fragments.

The loading of ore and waste at Morenci is accomplished with a full-revolving electric shovel equipped with a $4\frac{1}{2}$-yard dipper (Figure 6). A bulldozer aids in leveling the bench and scraping stray rock towards the reach of the shovel. It also serves to move the spillage from the area of the track. The ore is loaded in trains of ten 40-ton side dump cars, each equipped with axleless trucks and roller bearings, while the waste is loaded in trains of nine 30-ton cars of equivalent design (Figure 7). Sufficient cars or trains are available at the shovels to maintain a shovel efficiency of 87 per cent. Clearance, then, is another important factor in the planning of the open-pit mining operation. There must be sufficient clearance and overhead to permit unrestricted operation of the shovel, and there must be sufficient track clearance to permit the unrestricted movement of the bulldozer (Figures 8 and 9).

Naturally, the tracks on the benches and waste dumps cannot be aligned and surfaced as well as main-line tracks. Settlement on the fills and uneven floor on the benches makes surfacing difficult. The constant moving of tracks on both the waste dumps and the benches prevents good track alignment. As a result locomotives and rolling stock are designed to meet this problem, and the locomotive, particularly, must successfully withstand short-time overloads when negotiating uneven track and severe grades.

As explained in this description of the Morenci operations, open-pit mining consists of the removal of ore and waste from a series of shelves or benches, one above the other, and each operates as a separate mine. The operation may be either a pit operation or the tearing down of a mountain. Benches are employed in either case. The actual mining consists of blasting down ore, loading in suitable dump cars, and hauling ore to the mill or reduction plant. The haulageway includes permanent tracks and portable tracks. The permanent tracks are located between the mine and mill and also include the storage yards. The portable tracks are located on the benches and on the waste dumps. Switchbacks that are necessary for ascending from one bench to the next are usually permanent tracks. The overhead trolley system must correspond to the track construction. It must be either permanent or portable.

Progress of Electrification at Large Western Mines

The four large open-pit copper mines located in the West and Southwest, that are either wholly or partially electrified, are moving a daily tonnage of approximately 300,000 tons of ore and waste. This material represents more than 6,000 carloads and is handled with 100 electric locomotives over 200 miles of track. The locomotives at the Utah Copper Company, and also the two Nevada Consolidated Copper Corporation's operations at McGill, Nev., and Santa Rita, N.Mex., are 85-ton machines, whereas the 16 locomotives at Morenci are 125-ton machines. All mines operate with an overhead trolley voltage of 750 volts direct current. The combined substation capacity of the four electrifications for traction purposes is 15,000 kw, and the combined locomotive capacity is 100,000 horsepower.

Overhead Distribution System

The overhead distribution system performs a very important part in the operation of the open-pit mine, and is not merely "a place to park the pantograph." The steam locomotive requires its coaling equipment, its water plant, and its cinder pits. The diesel-electric locomotive requires its fuel storage and its fuel distribution system. The electric locomotive requires its substations and its overhead distribution system. Therefore, the electric distribution system becomes the auxiliary equipment for the electric locomotive. The distribution system is the fueling system.

The specifications for the two types of overhead systems, permanent and portable, are quite different. The permanent track is operated with the usual type of pantograph mounted on the roof of the cab, while the portable track is operated with a side-arm collector. The trolley wire is over the track center on permanent right of way and offset to the

Figure 1. Over 6,000 cars of ore and waste are hauled daily by electric locomotives in the large open-pit copper mines of the United States

Figure 2. The electrification of open-pit mines has become an important factor in the field of heavy traction

Figure 3. During preliminary stripping at Morenci, waste material was used for roadways and railroad fills

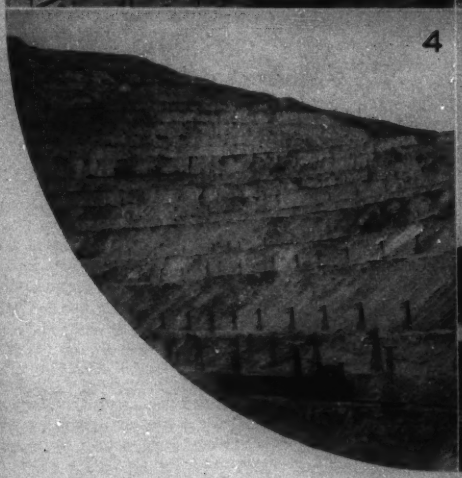

Figure 4. Each bench represents a separate or independent mining operation

Figure 5. Ore is broken away from benches by blasting, the length of the blasted section often extending a distance of 1,000 feet

Figure 6. Full-revolving electric shovels with 4 1/2-yard dippers loaded 22 1/2-yard dump trucks during preliminary digging in at Morenci

side of the track along the portable sections. We will describe the portable overhead first.

Portable Overhead System

The portable overhead system is used at any location where it is necessary to move the track at frequent intervals. The tracks on the benches are moved towards the face as mining progresses, and the tracks along the waste dump are moved towards the shoulder of the dump as the dump is filled out. On the bench tracks, head clearance must be maintained for loading, since the dipper of the shovel reaches over the center line of track. Crane equipment is frequently operated over both the bench tracks and the dump tracks; therefore, overhead clearance is necessary over these tracks. The usual offset of trolley wire from the center of track is from 10 to 16 feet. Of course, the offset on the benches is on the side opposite the shovel.

Portable structures are usually steel, either constructed of fabricated shapes or pipe. Owing to the constant handling, a wooden structure does not have sufficient life and is easily splintered. The pipe structure is the simplest and requires less maintenance.

One of the simplest pipe structures is used on the Utah operations at Bingham. This structure consists of a five-inch pipe embedded in a concrete footing and supporting, at its top, a bracket arm which in turn, supports the trolley wire. The concrete footing is elongated, as illustrated in Figure 10 and is equivalent to a sled or stoneboat in contour. It is equipped with a large eye bolt for pulling and can also be shoved into position with a bulldozer. This type of portable structure is easily transported from one bench to another and can be moved easily as mining progresses. A similar structure is used by the Canadian Johns-Manville Company for the mining of asbestos at their open-pit operation at Asbestos, Que., Can. This structure, however, is fabricated of lighter pipe. The illustration in Figure 11 shows how the footing is spread and mounted on stringers. This structure does not require a bracket arm for supporting the trolley wire; the gooseneck upper end of the main pipe performs this function. This type of structure has no flexibility from the standpoint of trolley-wire alignment. The entire structure must be moved along the ground to obtain this feature. Because of its lightness it is easy to move, but the curved arm does not have ample reach for some types of collectors.

One of the most recent and useful types of portable supporting structures is used at the new Katanga copper mine in the Belgian Congo. This structure, Figure 12, employs a five-inch tubular pole, a base, a bracket arm, and a special pole collar. The pole is supported in a cast-iron socket. The pole band has a large vertical hole or socket into which a pin on the bracket is inserted. A pad on the lower end of the knee brace lays against the pole for additional support. Since the center of rotation of the bracket arm about the pin does not coincide with the center of rotation of the pad, very little swing can be obtained by the bracket arm. However, there is sufficient clearance between the pin and the socket in the pole band to permit some movement, thus providing relief in the bracket arm in case the trolley-wire tension becomes unequal on either side of the pole.

To install the structure, the cast-iron socket is first placed in position. The socket may either be attached to a sled, in which case it is integral with the sled, or it may be spiked to extended cross ties. Next, the pole is inserted and keyed in the socket. This is usually a crane job with the locomotive crane pulling a flat car on which the structure material is loaded. The bracket arm is then lifted and its pin dropped into the socket in the pole band, the pole band having first been attached to the pole at the proper height before the pole is set in the base. The trolley wire is then strung and tensioned.

When the portable structures are hauled to new locations, the assembly procedure is sometimes altered. Another pole band is attached to the pole at a location about five feet above the ground. After the five-inch pipe has been dropped and keyed into the base, the pole bracket is then attached to this second pole band nearer the ground. At this height the lineman strings the trolley wire. After the wire is in place the brackets are lifted, one at a time, and placed on the pole bands at the top of the poles and at the proper height. Of course, the trolley wire is slack when the bracket arms are lifted; otherwise, the wire would tend to tip the poles. After the bracket arms are in place at the top of the pole, the trolley wire is tensioned and clamped.

A special type of trolley clamp is used for portable structures (Figure 13). This clamp provides not only the usual jaws for clamping the grooved trolley wire but also an opening above the jaws where the wire can be supported but not clamped. When the overhead system is in operation, the trolley wire is clamped in the lower part of the jaws and cannot be pulled through the jaws, but, while the structures are being moved, the trolley wire is held loosely in the opening above the clamps. Thus, the trolley wire is free to slide longitudinally when the poles are moved to a new position. After the structures are in place the trolley wire is tensioned by pulling the free end. The wire is then dropped into the lower portion of the clamps, and the jaws are tightened on the wire. The reverse of this operation is necessary when it is time to move the poles to another location. The jaws of the trolley-wire clamp are first loosened, and the trolley wire is pushed up and into the upper recess. The jaws are then tightened again in order to prevent the wire from falling out of the clamp.

The trolley clamp is usually insulated with a composition hanger with a malleable-iron protecting shell which withstands the flying rock fragments.

The fabricated structure illustrated in Figure 15 supports both the 750-volt d-c trolley wire and the 5,500-volt a-c electric-shovel circuit at both Utah Copper and the Santa Rita operation of the Nevada Consolidated Copper Corporation. In some instances the d-c feeder is also carried on the portable structures; however, the method of feeding the bench tracks does not require longitudinal feeder.

The installation of over 2,000 portable structures at the Bingham mine of the Utah Copper Company has demonstrated the usefulness of this type of haulage. Some of the original locomotives at Bingham were equipped with storage batteries to be used for the supply of energy in sections of waste dumps and other locations. It was thought that portable poles could not be used. Today all operations are supplied with an overhead trolley wire, batteries having disappeared from the scene. With adequate overhead clearance and properly designed structures there is no interference with loading and unloading, and the portable system can be moved quickly and cheaply. With a force consisting of a crane, three pit crews for the track, and two electricians, Utah moves 3,000 feet of track and portable overhead in five hours.

Permanent Overhead System

Two types of overhead are used on permanent track. Both types must provide clearances for pantograph operation.

Figure 7. 125-ton 750-volt locomotive operating at Morenci

Direct suspension, usually requiring supplementary feeder, is selected for slow speeds and full load currents below 1,000 amperes. Catenary overhead is selected to reduce initial cost and the number of supporting structures and to provide a better means for the supplying and collection of high currents. The choice of the distribution system, therefore, is based on the limitations and specifications of each electrification. As examples, the recent Katanga installation in the Belgian Congo with 66-ton locomotives is constructed with direct suspension using a single 4/0 contact wire on permanent or main-line sections, whereas the Morenci mine of Phelps Dodge Corporation with 125-ton locomotives is constructed with a compound catenary system consisting of a 350,000-centimeter hard-drawn copper main messenger cable, a 3/0 19-wire hard-drawn copper intermediate messenger, and 4/0-grooved hard-drawn copper contact wire. As a general rule, yards are constructed with light catenary in order to reduce the number of supporting structures and provide greater visibility, as well as man clearance around cars. The Utah Copper Company and the Nevada Consolidated Copper Corporation have installed many miles of light catenary along permanent tracks including storage yards, crusher yards, and main haulage out of the mines. The light catenary consists of a 7/16 Siemens-Martin messenger cable supporting a 4/0-grooved contact wire with flexible hangers.

Simplified Catenary Span

With reference to the Morenci mine of Phelps Dodge Corporation, the type of haulage made possible the selection of a modified type of catenary which, heretofore, has not been applied to mine electrification. Ease of construction and maintenance are the chief advantages of this type of catenary, but it is designed also for good current collection and feeder characteristics. The catenary span is spaced 120 feet on tangent, and on curves it is spaced 80, 60, and 50 feet, depending on the degree of curvature. Most of the curves, however, use 80-foot spacing.

With reference to Figure 16, it may be observed that three main-line hangers

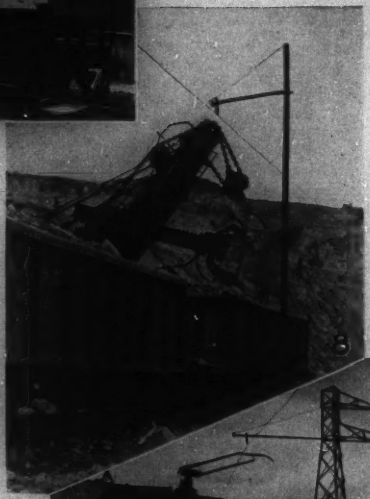

Figure 8. Unrestricted overhead clearance must be provided for the operation of the electric shovel

Figure 9. Side-arm collection provides overhead clearance for the movement of locomotive cranes

Figure 10. Portable structures consisting of tubular poles supported on concrete stoneboats are used on benches at Utah Copper Company

Figure 11. Canadian Johns-Manville Company, Ltd. portable pipe structure

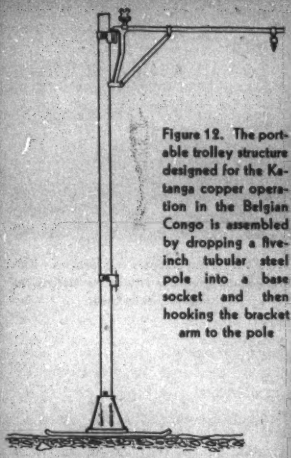

Figure 12. The portable trolley structure designed for the Katanga copper operation in the Belgian Congo is assembled by dropping a five-inch tubular steel pole into a base socket and then hooking the bracket arm to the pole

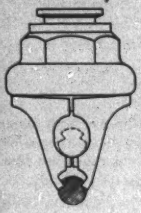

Figure 13. When a portable structure is to be moved, the grooved trolley wire is removed from the jaws of the clamp and inserted in an upper groove where the wire will slide freely

are used on the 120-foot spans. The end hangers are located 20 feet from each point of support, while the third hanger is located midway on the span. This main-messenger-hanger spacing divides the intermediate cable spans into 40-foot lengths. The trolley wire is supported by three clips attached at equal intervals to the intermediate cable. The center clip is two inches in length, whereas the two end clips are three inches in length. With this type of construction good contact between fittings and cable is obtained for the flow of electric energy from the messengers to the contact wire. As explained in the preceding description, a minimum number of hangers is required. The 120-foot span requires only two lengths of main-line hangers and two clips. The 80-, 60-, and 50-foot spans require additional lengths of main-line hangers, but the same two-clip construction is used throughout the entire line. With this type of catenary span the total number of main-messenger hangers will not exceed 9 for the spans indicated, whereas the total number of hangers for the conventional span might easily exceed 50 when the special length spans are considered.

Figure 14. Portable structures mounted on truck wheels are moved over short sections of rail on dump tracks of International Nickel Company

Figure 15. Fabricated structures support the 750-volt d-c trolley wire and the a-c shovel circuit at Utah Copper Company

Although tangent pole spacing on the Morenci electrification is only 120 feet, and the nominal pole spacing on light catenary at the mines of the Utah Copper Company and the two operations of the Nevada Consolidated Copper Corporation is 150 feet, the spacing of catenary spans is not limited to these dimensions, except by economy and physical limitations (Figure 17). These operations, from the standpoint of rolling stock, locomotives, and rail size (131 pounds at Morenci) are comparable to many large steam-road electrifications, and with sufficient main-line track would undoubtedly be built with structures spaced at 300-foot intervals.

A Bit of History

The Utah Copper Company electrified the crusher yards at both the Magna and Arthur plants in 1925 (Figure 18). Two 80-ton locomotives, formerly used by the Manufacturers' Railroad of St. Louis, were installed in these yards. The total trackage was slightly over eight miles. During 1936 a large part of this crusher-yard electrification was torn down, and one of the mills was partially dismantled. During the following year, however, because of improved market conditions, the mill was again placed in operation and this nine-year-old catenary system was rebuilt with scarcely any loss in line material. Naturally, the electrical department was adept in taking down and rebuilding overhead systems, since this is daily procedure for the open-pit mine electrification. The original system is in operation today.

Supporting Structures for Permanent Track

Supporting poles are either wood or steel. At the Utah Copper Company mines, wood poles are used on permanent haulage, with the exception of the yards. Wood poles have been used extensively at the Canadian Johns-Manville mines at Asbestos, Que. Long outside haulage tracks of the International Nickel Company, near Sudbury, Ont., are equipped with wood poles for supporting light catenary overhead. The

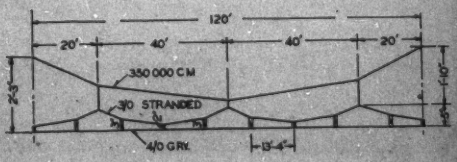

Figure 16. This catenary span reduces the number of main-catenary hangers to a minimum

other mine operators. The mine operator does not insist on numerous gadgets and changes in design, but insists on dependable equipment as well as simple equipment. The job of moving thousands of tons of material daily is dependent on a minimum of breakdowns and, since mining has become a production-line process, transportation must function satisfactorily. Simplicity, a synonym for low cost, is the first rule of mining.

The nucleus of the construction forces is gathered from the mine. The foremen are usually acquainted with the designs and procedure before actual building starts. Therefore, the builders take an active interest in the equipment and in the construction and become trained maintenance men before actual operation is initiated. This procedure ultimately reduces maintenance costs and, to a great extent, the necessity for servicing (Figure 23).

Costs

When it is realized, that at one large strip mine the cost of water for steam locomotives paid the power bill after electrification, few additional data are necessary to convince the mine operator that electrification is economical. At McGill, Nev., the cost of haulage was reduced, by the substitution of electric energy for steam, from 10 cents to 3.4 cents per ton. At Morenci the cost of electric haulage is only two cents per ton, or slightly less than one cent per ton-mile, a figure that compares with the average cost per ton-mile on class 1 railroads.

Advantages of Electrification

A specific example of the advantages of open-pit electrification is found at Bingham. Here the number of loaded cars in an ore train has increased 25 per cent, and speed has increased 25 per cent. Therefore, fewer locomotives are necessary per shovel.

In general, with electric operation, there is less track wear due to the articulated locomotive, and there are fewer car derailments. With electrification there is no burning of wood crossties, an expense which was once tremendous in large mines. The electric locomotive does not require the transportation of fuel and water, an operation which added a large amount to the cost of haulage. Engineers have greater vision while operating in and out of the pits, and the elimination of smoke helps pit operation, since good visibility is a big factor in the operation of a mine.

In conclusion, the electric locomotive is reliable. At the Bingham mine of the Utah Copper Company there are 65 locomotives, and there is rarely a time when more than two are in the shop. The electric locomotive is not affected by bad water, and its breathing apparatus is not susceptible to change in altitude. It consumes but one grade of fuel, and that is the best grade. The electric locomotive has proved a successful factor in the operation of large open-pit copper mines.

An Instrument for the Measurement of Large Alternating Currents

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FELLOW AIEE

Synopsis: An arrangement of the measurement and oscillographic recording of large alternating currents, consisting of a special air-core transformer and an amplifier, is described. The air-core transformer is wound on a flexible core of small cross section, permitting its easy linkage with the current to be measured without disturbing the circuit. The underlying theory of the air-core transformer is discussed, and the modifications necessary to make it suitable for measurement purposes are described.

THE measurement of large alternating currents, as required on the low-voltage side of resistance and flash welding transformers for instance, is an important problem, and many suggestions for satisfactory solutions have been made.[1]

The ordinary current transformer, such as used in almost all a-c measuring circuits, operates on the principle that in any iron-core transformer working with a low magnetic flux density in the iron core the total excitation resulting from the two windings is nearly zero. This means that the ampere turns produced by the meter winding equal the ampere turns or the amperes, in the case of a single conductor, of the current to be measured. Since the current density in the meter winding cannot, as a rule, be made higher than the current density in the primary conductor, which, it can be assumed, has been chosen as high as permissible with regard to the heating of the primary conductor, the copper cross section of the meter winding must at least equal the cross section of the primary conductor; the total space taken by the meter winding will be increased further by the insulation of this winding. In addition to this, the two windings must be made to link with a closed iron core. In low-voltage welding circuits every effort has been made usually to reduce the spread between the leads, or the "loop," to a minimum, and the insertion of a current transformer, which, for the reasons previously mentioned, necessarily will be bulky, is usually out of the question.

Suggestions have been made that a part of the welding circuit be used as a shunt for a meter. This scheme runs into difficulty from skin effects, especially for distorted wave shapes such as those that occur in flash-welding currents, and requires very careful placement of the leads to avoid inductive pickup. The calibration also presents some problems.

Air-core transformers have been used for the measurement of large alternating currents,[2] and this paper deals with a special arrangement of this type of transformer. Any air-core transformer is unsuitable for the measurement of currents without certain modifications, as will be evident from the following. Its operation is based on the fact that in the vicinity of a conductor carrying alternating current there will be an alternating magnetic field, the intensity of which will be proportional to the current, if no iron masses are close by. If a coil is placed in this field, a voltage will be induced in it, and this voltage may be used as an indication of the current. Since the induced voltage equals $M \times di/dt$, where M is the mutual inductance between the

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WALTHER RICHTER, now electrical engineer in the engineering development department of Allis-Chalmers Manufacturing Company, Milwaukee, Wis., was an independent consulting engineer at the time this paper was written.

The author expresses thanks for the suggestions of W. B. Crawford, B. J. Limpel, and A. Peals of the A. O. Smith Corporation, the laboratory in which the device described in this paper was developed.

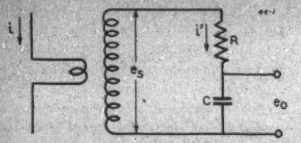


Figure 1. Circuit for electrical integration of an alternating voltage

primary conductor and the pickup coil, it is evident that the instantaneous values of this voltage are not proportional to the instantaneous values of the current, but rather to the instantaneous values of the rate of change of current. When a sinusoidal current of known frequency is dealt with, the voltage induced in the pickup coil will, of course, again be a sine wave, 90 degrees displaced against the current wave. In this case, the rms value of this voltage may be used safely as an indication of the current, as long as no phase relations are deduced from it. But let us assume now that the frequency of the current doubles, while its amplitude and rms value remain constant. Since di/dt doubles, the voltage in the pickup coil will also double. From this it is at once apparent that the air-core transformer fails to indicate the current by the induced voltage if the current has a distorted wave shape, that is, has harmonics. This is especially true in flash welding, but even in plain resistance welding the current may change in wave shape if electronic tubes are used to control the firing point in the cycle.

A second difficulty lies in the fact that the placement of the pickup coil determines the value of M and with it the magnitude of the induced voltage. This difficulty has been overcome to a large degree, however, by most of the workers in this field, by properly shaping and placing the pickup coil, and their method of approach has been utilized also in the present arrangement.

After the two essential problems of the air-core transformer have been stated thus, the methods of solving them will be discussed.

The voltage $e_s = M \times di/dt$, induced in the pickup coil, is a result of a differentiation of current, as the formula indicates. If the reversed operation, that is, an integration, is performed on it, the resulting wave will be a replica of the original current wave. This integration can be carried out electrically by the simple circuit shown in Figure 1. Let the periodic voltage e_s be applied to the series combination of R and C, and let the value of C be such, that its reactance is small compared with the value of R,

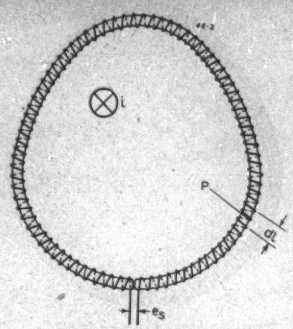


Figure 2. Linkage of toroid with current to be measured

even at the fundamental frequency of e_s. Under this condition the current through R and C will be determined essentially by the value of R only; that is, we can write without serious error

$$i' = \frac{e_s}{R} = \frac{M}{R} \times \frac{di}{dt} \qquad (1)$$

The voltage across the capacitor will be

$$e_0 = \frac{Q}{C} = \frac{\int i'dt}{C} = \frac{M}{R \times C} \times \int di = i \times \frac{M}{R \times C} \qquad (2)$$

Figure 3. Amplifier and integrating circuit

V1—6F5 tube	R2 — 10,000-ohm resistor
V2—6N7 tube	R3 —250,000-ohm resistor
V3—2A3 tube	R4 — 5,000-ohm resistor
V4—80 tube	R6 — 50,000-ohm resistor
C1—0.5-microfarad capacitor	R7 — 20,000-ohm resistor
C2—24-microfarad capacitor	R8 — 10,000-ohm resistor
C3—1-microfarad capacitor	R9 — 10,000-ohm potential divider
C4—100-microfarad capacitor	R10— 375-ohm resistor
C5—16-microfarad capacitor	
C6—50-microfarad capacitor	
R1 —150,000-ohm resistor	

It must, of course, be realized that for this relation to be strictly true, the capacitor would have to be infinitely large, so that all the voltage e_s appears across R. However, the larger C, the smaller the output voltage e_0, and the higher the amplification will have to be, before use can be made of this voltage. In the present instrument R=100,000 ohms, C= 0.5 microfarad, which makes the reactance of the capacitor at 60 cycles per second roughly five per cent of the value of the resistance; this seemed to be a fair compromise between accuracy and amplifier requirements.

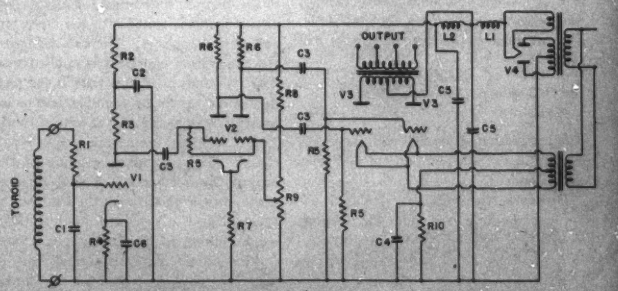
To make the voltage induced in the pickup coil as nearly independent as possible of the position of the coil, it must have the proper shape and must be placed according to certain fundamentals. The basic law of electromagnetism states that the line integral of the tangential component of the magnetic-field intensity around any closed path equals 0.4 π times the exciting ampere turns linking with the path, that is

$$\oint H_t dl = 0.4\pi i \qquad (3)$$

where H_t is the component tangential to the path around which the integration is to be performed.

Suppose we surround the current with a toroidal* coil, wound on a flexible core, a length of heavy-walled rubber tubing, for instance. The winding is distributed uniformly over the whole length. Let n' be the number of turns per centimeter, so that the total number of turns N is equal to $n' \times 1$, where 1 is the length of

*The terms toroid and toroidal are used here and in the following for the sake of brevity, although the coil described here does not have to be a true toroid. A toroid is defined as the surface generated by the rotation of a plane closed curve around an axis lying in its plane. In this paper we mean a coil wound on a surface generated by moving a plane closed curve along a closed path in such a manner that its plane is always perpendicular to the direction of the motion, which is a cumbersome way of saying: Take a heavy-walled rubber tube, make a "doughnut" out of it, and place a uniformly distributed winding on it; then deform the "doughnut" any way you like (as long as you do not squeeze its cross section).



the tubing. The cross section of the core, that is, of the tubing, is held small enough so that the average magnetic density over the whole cross section can be considered, without serious error, equal to the magnetic density existing along the axis of the toroid at any given point P. Since the plane of each individual turn is essentially at right angles to the axis, a voltage caused by a changing magnetic field will be induced only by the component tangential to the axis. If A is the area of one coil turn, which in most practical cases will be very nearly equal to the cross section of the flexible core, in square centimeters, the voltage induced over the length dl of the coil will be

$$de_0 = A \times n' \times dl \times \frac{dH_1}{dt} \times 10^{-8} \text{ volts} \qquad (4)$$

and the voltage produced by the whole coil, forming a closed path, will be

$$e_0 = A \times n' \times \oint \frac{dH_1}{dt}\, dl \times 10^{-8} \text{ volts} \qquad (5)$$

Differentiating equation 3 with respect to time results in

$$\oint \frac{dH_1}{dt} \times dl = 0.4\pi \frac{di}{dt} \qquad (6)$$

and substituting this into equation 5 gives

$$e_0 = A \times n' \times 0.4\pi \frac{di}{dt} \times 10^{-8} \text{ volts} \qquad (7)$$

which is independent of the position and length of the loop.

To obtain an idea of the order of magnitude of the voltages that can be expected, suppose we wind number 30 wire on a rubber tubing of one square centimeter cross section (about $^9/_{16}$ inch diameter). Number 30 enamel will give about 90 turns per inch, or 35 turns per centimeter, if we use a single-layer winding. Suppose that a sinusoidal current of 1,000 (rms) amperes with a frequency of 60 cycles per second is made to pass through a toroid made of this tubing. Considering the fact that the maximum rate of change of a sinusoidally varying quantity equals $2\pi f$ times the amplitude, the rms value of the induced voltage will be

$$e_0 = 1 \times 35 \times 0.4\pi \times 1{,}000 \times 2\pi 60 \times 10^{-8} = 0.166 \text{ volt} \qquad (7a)$$

The production of one volt will, therefore, require about 6,000 amperes at 60 cycles per second.

However, the voltage calculated according to equation 7 under the assumption of a sinusoidal current, as in equation 7a, is not the one to be measured, as explained earlier; the integrating circuit not only reduces the actual voltage available for measuring to about five per cent of the voltage induced in the toroid, but also makes it appear across a circuit element having a high impedance compared with the impedance of the usual low-range rms voltmeter. It is, therefore, quite obvious that an amplifier will be needed to accomplish the measurement. It is of importance that this amplifier have as flat a response as possible, if the output of it is to be used for the operation of an oscillograph, although there is nothing gained by extending the frequency range beyond that of the oscillograph. For a string oscillograph a flat response of the amplifier from 60 to 3,000 cycles will, therefore, be entirely satisfactory. Figure 3 shows the diagram of an amplifier which has been found satisfactory for the purpose. Further refinements, such as inverse feedback, can, of course, be introduced to increase the accuracy of the measurement or to improve the stability and permanency of calibration. The need for these will be dictated by the nature of the problem with which one has to deal. Examination of the diagram shows that the integrating circuit is incorporated into the input circuit of the amplifier. The voltage across the integrating capacitor is applied to a 6*F*5; the output of this tube is fed to a 6*N*7 which serves as amplifier and phase inverter, so that the pair of output tubes, 2*A*3's, receives essentially a push–pull signal. The secondary winding of the output transformer has several taps, so that a proper match with the load can be accomplished. Any high-quality standard amplifier, to which the special integrating circuit has been added, can, of course, be used in place of the one shown.

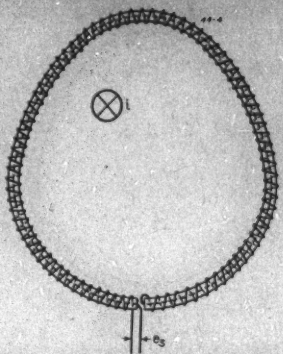


Figure 4. Arrangement of return lead to eliminate effect of magnetic fields not due to current to be measured

Calibration of the device is relatively simple. In contrast to a shunt method, it is not necessary to have a calibrating current available of the same order of magnitude as the currents to be measured. By linking the calibrating current several times with the toroid coil, its magnitude can be reduced to almost any desired value. Thus, if, for instance, a shunt coil of a d-c machine with a known number of turns is available, currents in the order of a few amperes can be used for calibration. Instead of using a known current for calibration, it is also possible to calculate the voltage which will be induced by a given current of sinusoidal wave shape and known frequency, as shown in equation 7a. For the toroid to which this equation refers, we had found a voltage of 166 millivolts induced by a 1,000 ampere rms, 60-cycle per second sinusoidal current. By applying 166 millivolts, 60 cycles per second, obtained from any convenient 60-cycle source (such as a voltage divider) to the given integrating circuit and amplifier, and observing the output of the amplifier, calibration is obtained. Because of the action of the integrating circuit, as explained previously, the calibration will be correct for any wave shape.

An interesting detail in connection with the leads of the toroid coil should be pointed out. During the initial experiments, when the leads were brought out, as in Figure 2, it was noticed that the voltage induced in the coil was not independent of the position of the coil with respect to the conductor. At first it was thought that this was due to the cross section of the toroid not being small enough. The true explanation, however, is that the toroid itself forms a loop, and any field will induce a voltage in it, regardless of whether a current passes through it or not. As soon as this was recognized as the cause, the remedy was obvious: one end of the winding should be brought back along or, ideally, on the axis of the helix, as shown in Figure 4. As soon as this was done, the position of the loop no longer had influence on the magnitude of the induced voltage. Another way to accomplish the same result, at the same time increasing the output voltage, is to wind another layer of turns on the toroid, progressing with this layer in the opposite direction.

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2. A New General-Purpose Meter for Resistance Welding, C. Stansbury. *The Welding Journal*, volume 14, September 1943, pages 32–5.

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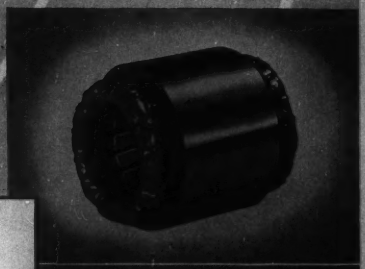

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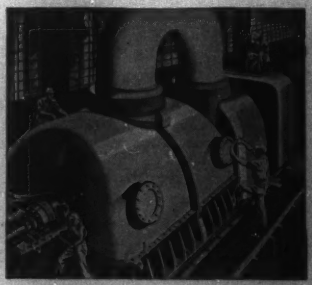

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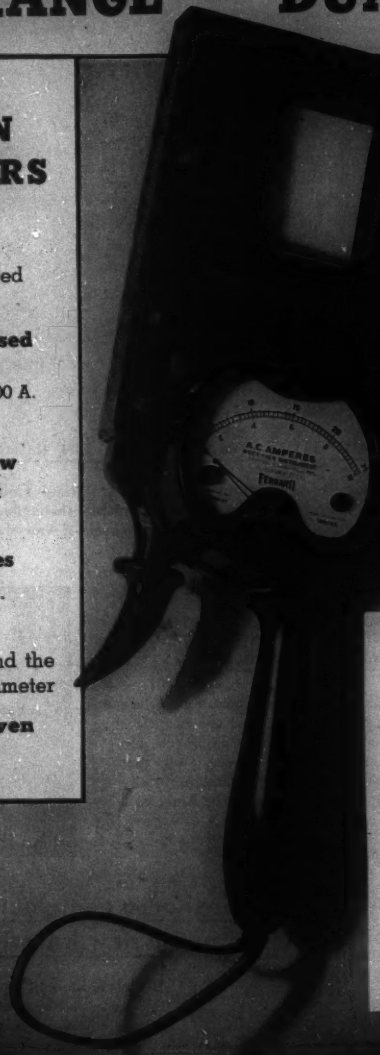

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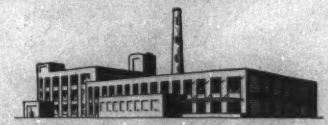

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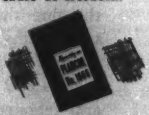

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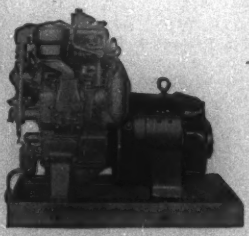

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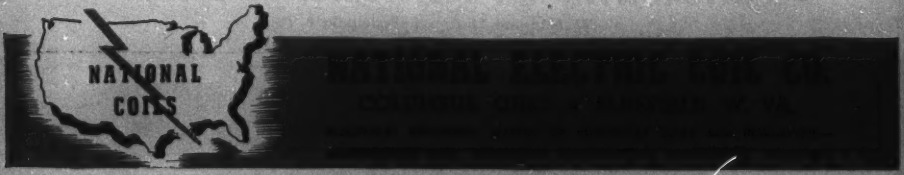

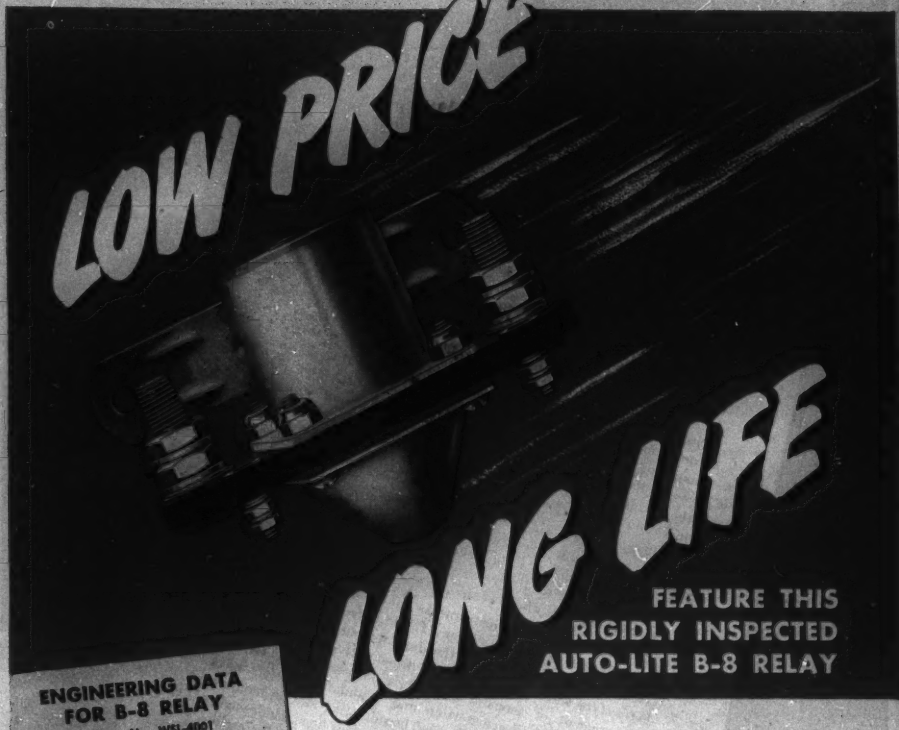

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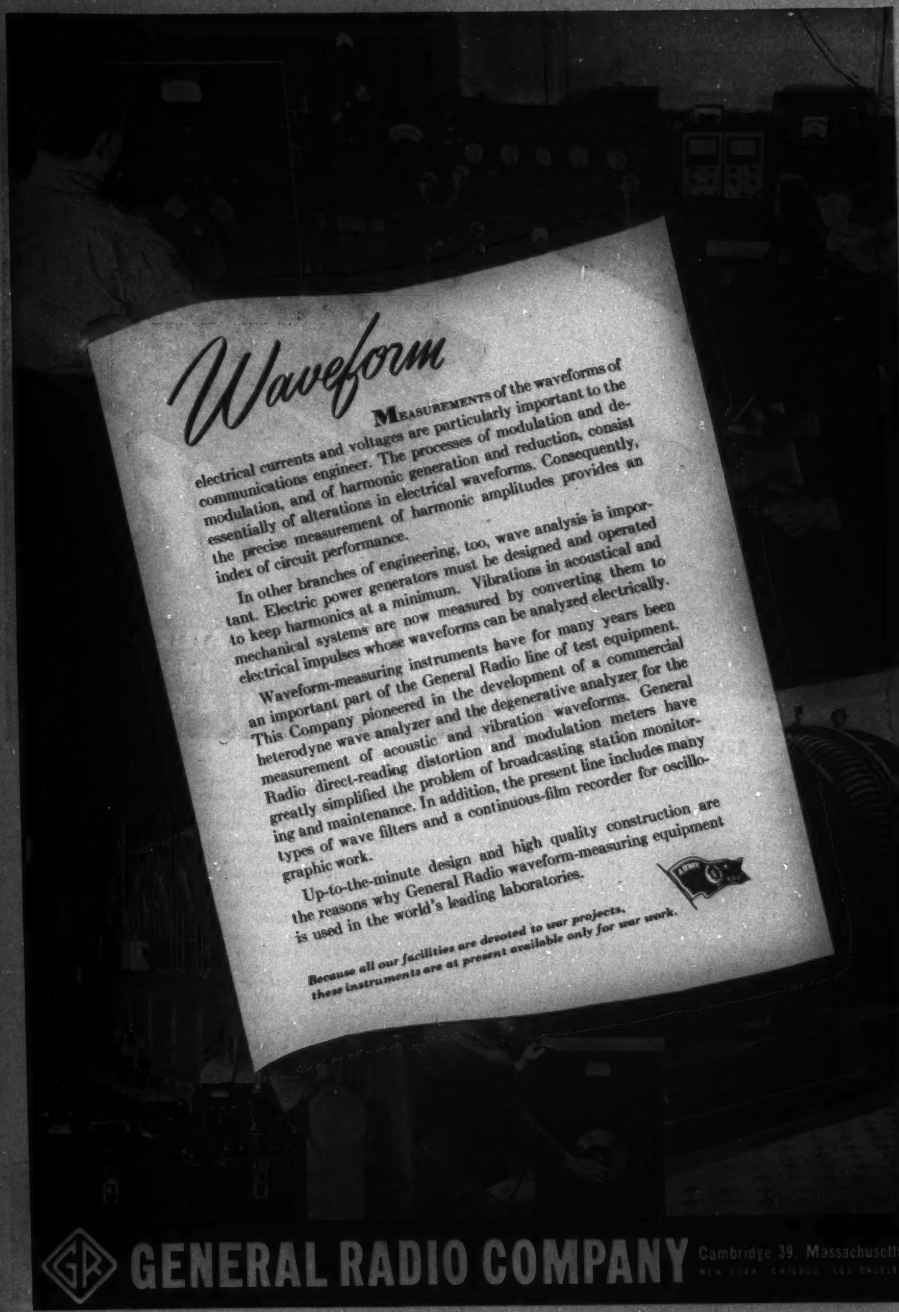
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Because all our facilities are devoted to war projects, these instruments are at present available only for war work.
GENERAL RADIO COMPANY
Cambridge 39, Massachusetts
NEW YORK CHICAGO LOS ANGELES

"Give us SLEEVING that's RUGGED..."

Operator at the Muskegon plant of Anaconda Wire & Cable Co. slipping Natvar sleeving on coil leads.

THAT was Anaconda Wire & Cable Company's first requirement for the sleeving to be used on coils they are building for certain vital war equipment.

"Give us sleeving that's rugged . . . it has to do more than pass the standard tests, because it will have to take plenty of punishment after it leaves here. We know where these coils are going . . . and we know *they've got to stand up!*

"And another thing — most of them are needed *yesterday*, so we're shipping 'em out each day as soon as they pass final tests. We run into trouble if the sleeving isn't smooth on the inside — it slows us down because most of our leads are dead soft or stranded. It may sound like a little thing — but it's important.

"Besides, we want fast color and fast delivery."

What are *your* requirements? Write, wire, or phone us, and we will ship at once, either from nearby wholesaler's stock or direct from our own.

Natvar

- Varnished cambric—straight cut and bias
- Varnished cable tape
- Varnished canvas
- Varnished duck
- Varnished cellulose acetate
- Varnished papers
- Varnished tubings and sleevings
- Varnished identification markers
- Lacquered tubings and sleevings
- Extruded Vinylite tubings
- Extruded Vinylite identification markers

Write for bulletins

THE NATIONAL VARNISHED PRODUCTS Corporation

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CABLE ADDRESS NATVAR: RAHWAY, N. J.

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I-EVP-3

The Model "U" shown above is 12" in diameter and rated at 1000 watts. The Model "L" is 4" in diameter and rated at 150 watts. Other models in this series of larger units are 10", 8", 6" and 5" in diameter and rated at 750, 500, 300 and 225 watts respectively. These rheostats handle tough applications with ease. They provide permanently smooth, close, trouble-free control on big jobs. Made in single or tandem assemblies, in straight or tapered winding, from 25 watts to 1000 watts.

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Write on company letterhead for 96-page Industrial Catalog and Engineering Manual No. 40.

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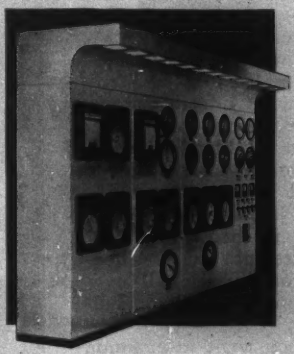

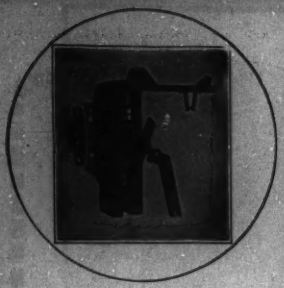

200 Ampere, Catalog 275

Compact

A New Jersey engineer had the fallacious idea that he couldn't get eighteen 400 ampere disconnecting switches in an available space of 21 feet.

Then he learned that Matthews Disconnecting Switches were only 3⅞ inches wide in the 200 and 400 ampere ratings and only 4¾ inches wide in the 600 ampere rating, and that they are all rated 7500 volts. His problem was solved and he had ample space to do a neat job.

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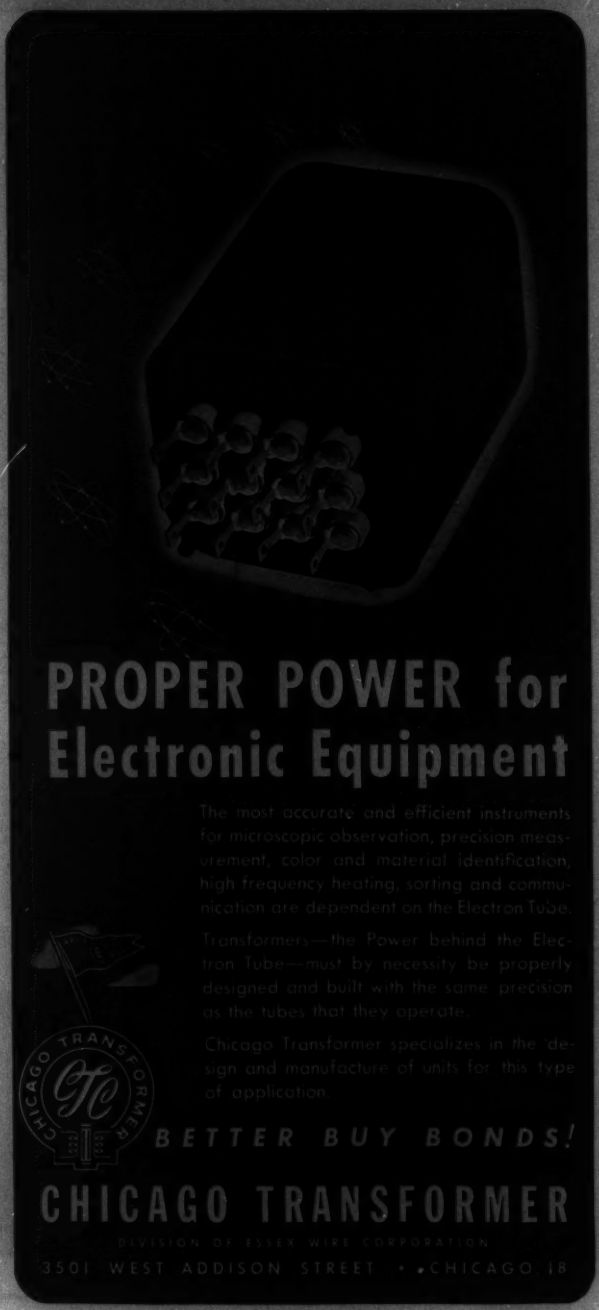
600 Ampere, Catalog 675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Transformers—the Power behind the Electron Tube—must by necessity be properly designed and built with the same precision as the tubes that they operate.
Chicago Transformer specializes in the design and manufacture of units for this type of application.
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Announcing . . . Type PC

A new

Its Advantages

1. Insulation maintained thoroughly saturated with compound at all times.
2. Internal pressure is stabilized within prescribed limits.
3. Controlled sheath stresses. There is no repeated expansion and contraction, no fatigue or splitting of lead.
4. Pressure along cable line is uniform, not variable from joint to center of section to joint.
5. Sheath supervision is not required. Failure rates from other than inherent causes too low to justify supervision.
6. Interchangeability. Cable can be spliced to existing solid type cable without difficulty.
7. Increased current carrying capacity. Many present-day limits are based on allowable sheath stress — type PC Cable controls these stresses.
8. Improvement in operating voltage stress is possible, since ionization and gas inclusions are eliminated.
9. Reduced overall transmission cost per KVA mile.
10. Strategic materials and metals may be saved.

Pressure Compensated Cable

development in Paper Insulated Power Cables

● HERE is an improved power cable that offers you all the usual advantages inherent in paper insulated cable, plus the additional feature of much greater operating reliability.

Type PC Cable differs from the ordinary "solid-type" paper insulated cable in only one respect—but an important one. Included in the impregnated fillers are one or more small lead tubes. By this unique and simple expedient is obtained stabilization of operating pressures within fixed limits.

The pressure-compensating "gas cushion" is the secret

Note the schematic diagram below. The helical tubes are filled with dry nitrogen gas and are perforated at intervals of approximately four times the length of lay. Perforations in the tubes are staggered so that there is a perforation—hence, contact between insulating compound and gas—every one and one-third lengths of lay. During manufacture, excess quantities of the cable saturant are forced into the several perforations.

When the cable is installed, slugs of the compound gradually collect in the low portions of the tubes. The gas collects in the domes.

During the application of the load, which causes expansion of the compound and increases the internal pressure, additional saturant is forced into the tubes through the perforations.

This merely compresses the gas entrapped between the slugs and thus acts as a cushion to prevent development of pressures which would normally stretch the lead sheath.

Pressure is very uniform along the entire cable length—there are no points of concentrated pressure—due to the fact that the maximum distance to points of pressure stabilization are equal to one-half the spacing between perforations.

When the cable cools and the oil saturant contracts, the compressed gas in the tubes forces the oil back again into the cable, thus preventing wide swings from pressure to vacuum as encountered in ordinary "solid-type" cable.

In PRESSURE COMPENSATED Type PC CABLE the positive pressure operating characteristics of "oil-filled" and "gas-filled" cables are obtained at very moderate increase in cable cost and with practically no increase in either the cost or difficulties of installation and supervision. A bulletin on PC Cable has just been issued. Send for it.

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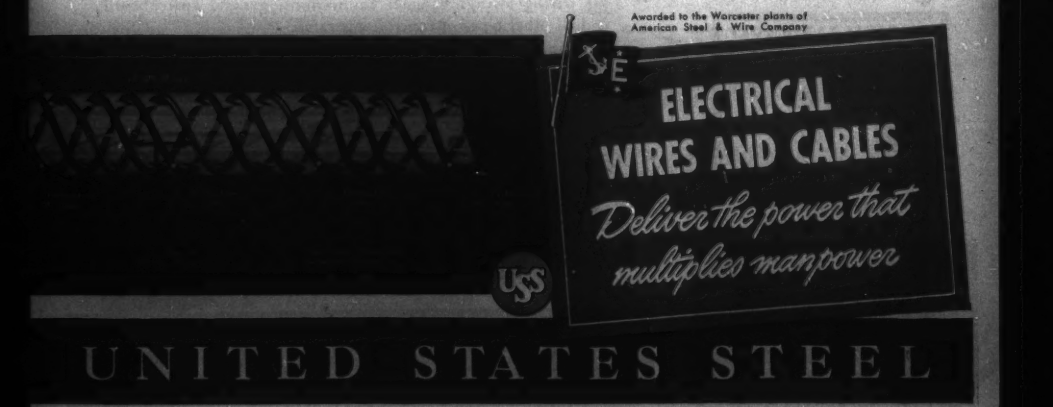

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POWER NEEDS PROTECTION TOO!

TODAY war industries are guarded night and day by watchful plant policemen; vital power station equipment is protected by high barbed wire fences; powerful floodlights are on the alert to expose any saboteurs; but how about the wiring in your power plant? Power needs protection too—

And there's no better protection for general wiring in power plants where operating conditions are severe than Deltabeston Asbestos-insulated Wires and Cables. Deltabeston is built to withstand peak-load production day in and day out, the year round. Where excessive heat, high humidity and corrosive vapors play hob with electrical equipment, Deltabeston performs with the utmost dependability.

Here are just a few of the numerous Deltabeston Cables with the heat-resistant insulation that are helping to speed the day of Victory:

Deltabeston Power Cable Types AVA or AVL for general wiring in power plants, steel mills, boiler rooms and in other torrid zones where constant high temperatures prevail.

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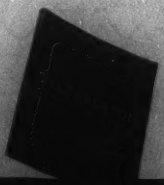
It's yours for the asking. Write to Section Y141-32, Appliance and Merchandise Dept., General Electric Company, Bridgeport, Conn. Deltabeston Wires and Cables are distributed nationally by Graybar Electric Co., General Electric Supply Corp. and other G-E Merchandise Distributors.



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Such equipment must work dependably and *constantly*. High speed production has brought about an acute problem. These instruments are in danger of overwork. *Many are irreplaceable.*

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Efficient fusing prevents damage by short circuits—burnouts—saves valuable instruments—protects them from inexperienced operators.

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So important is fusing that many plants and laboratories are making complete surveys of their equipment, and installing *new fuses throughout.*

Littelfuse will be glad to help you with practicable suggestions on fusing instruments and other equipment. Feel free to call on us.

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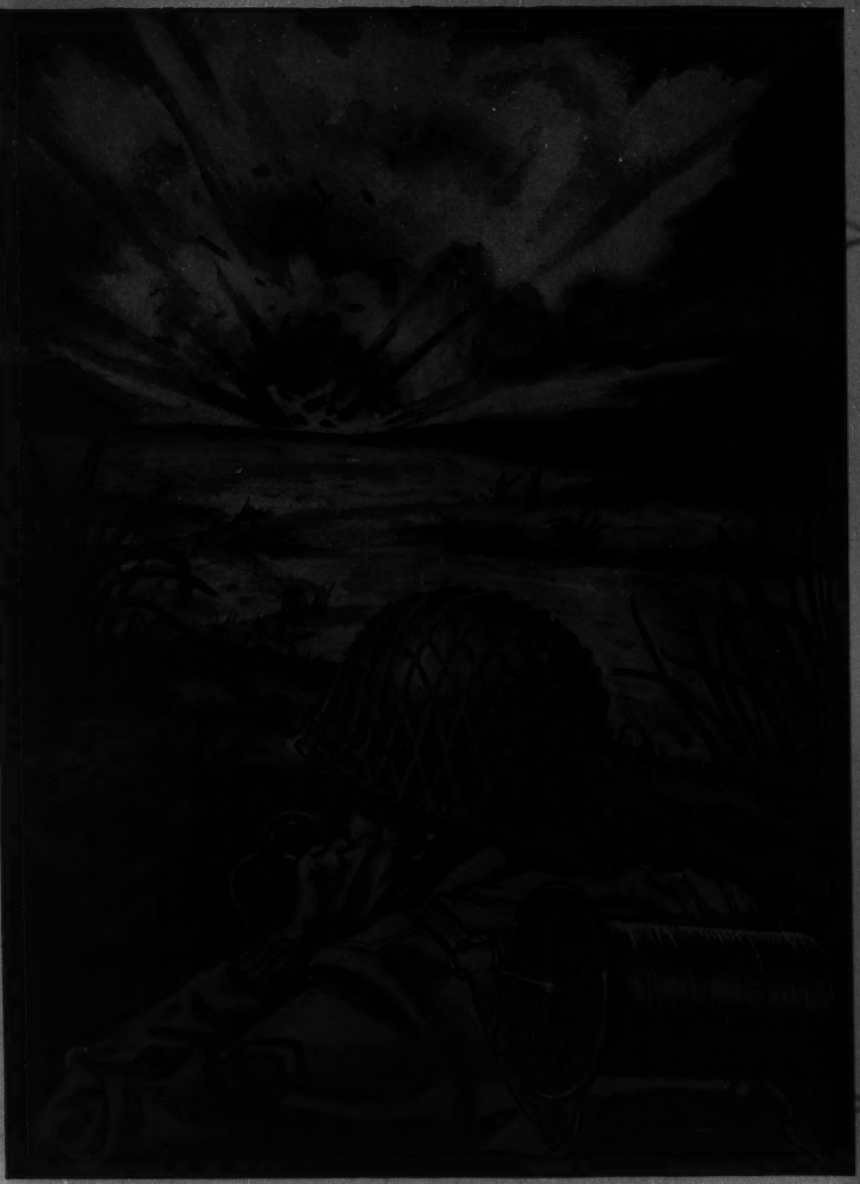

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UNITED STATES

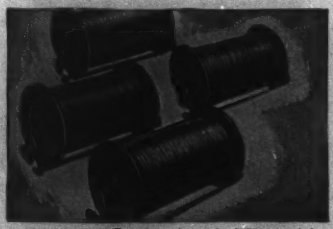
Miles from nowhere —but the message gets through

He'd crawled, run, crawled again. Now he was far ahead of his company... into enemy territory... surrounded... cut off completely from American forces except for a strand of lightweight wire... Laytex Assault Wire.

But his messages got through surely and clearly... made possible a successful advance.

Laytex Assault Wire is made expressly for jobs like this. It's extremely lightweight... yet tough enough to be used by advance scouts.

The use of such lightweight small diameter wire is possible only because the insulation is of such high quality—has high resistance to moisture, withstands a wide range of temperature changes and does not become embrittled when subjected to vibration and shock. Laytex Assault Wire has a talking distance of over five miles.



LIGHTWEIGHT Laytex Assault Wire weighs only thirty pounds per mile. This means that an advance scout can carry ample wire while pushing ahead.

SPECIALLY DEVELOPED for front line service, Laytex Assault Wire is hard at work in Europe, Asia, the South Pacific.

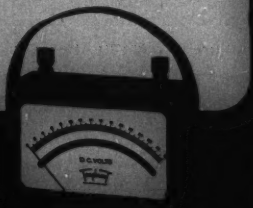
LAYTEX ASSAULT WIRE is unaffected by moisture or temperature changes because of the high quality of the insulation. This means it can be laid and used successfully regardless of climate or terrain.

FIVE MILES LONG—but messages get through clearly. Laytex Assault Wire, tested and retested for quality, has a proven talking distance of more than five miles.

RUBBER COMPANY

MODEL 625—0-30 D.C. VOLT METER

This is one of today's most popular portables. The new design has a hinged dial cover for added protection; insulated molded case and hand calibrated mirror scale 4.58" in length. Furnished to an accuracy within one-half of 1%. THE TRIPLETT ELECTRICAL INSTRUMENT COMPANY, BLUFFTON, O.



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Specialists for over a generation in

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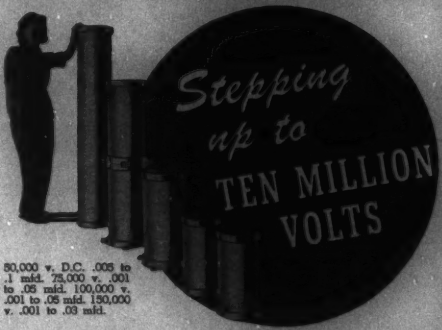


Stepping up to TEN MILLION VOLTS

50,000 v. D.C. .005 to .1 mid. 75,000 v. .001 to .05 mid. 100,000 v. .001 to .05 mid. 150,000 v. .001 to .03 mid.

● Charged in parallel, discharged in series, these capacitors provide for voltages up to 10,000,000 and over for certain deep-penetration X-ray and impulse generator applications. For usual X-ray work, single units operate up to 180,000 volts.

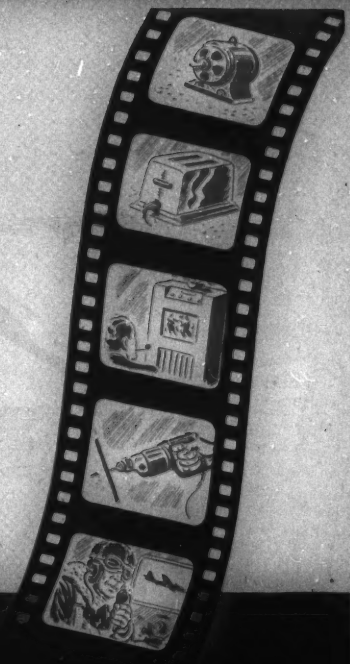
Aerovox Type '36 capacitors are designed for just such service. Multi-layer paper sections, oil-impregnated, oil-filled, housed in sturdy tubular bakelite cases. Choice of metal cap terminals facilitates stack mounting and connections. Sections are of matched capacitance insuring uniform voltage gradient throughout length of capacitor.

New catalog, listing an outstanding line of heavy-duty capacitors, sent on request. Write on business letterhead.

AEROVOX Capacitors

INDIVIDUALLY TESTED

Integrity IN WIRE...?



CAN WIRE be said to have *integrity?* Yes, that is the one quality that, through the years, we have built into Roebling Electric Wires and Cables. So that you can depend on Roebling products...

You need that kind of dependability, when you are buying wire for the products that will bear your name. Whether it's for today's electric motor, tomorrow's appliance...whether it's rubber covered wire for an industrial electric tool or magnet wire for an aircraft radio, you can be sure that the Roebling name guarantees the same fine performance you build into the product in which the wire is used.

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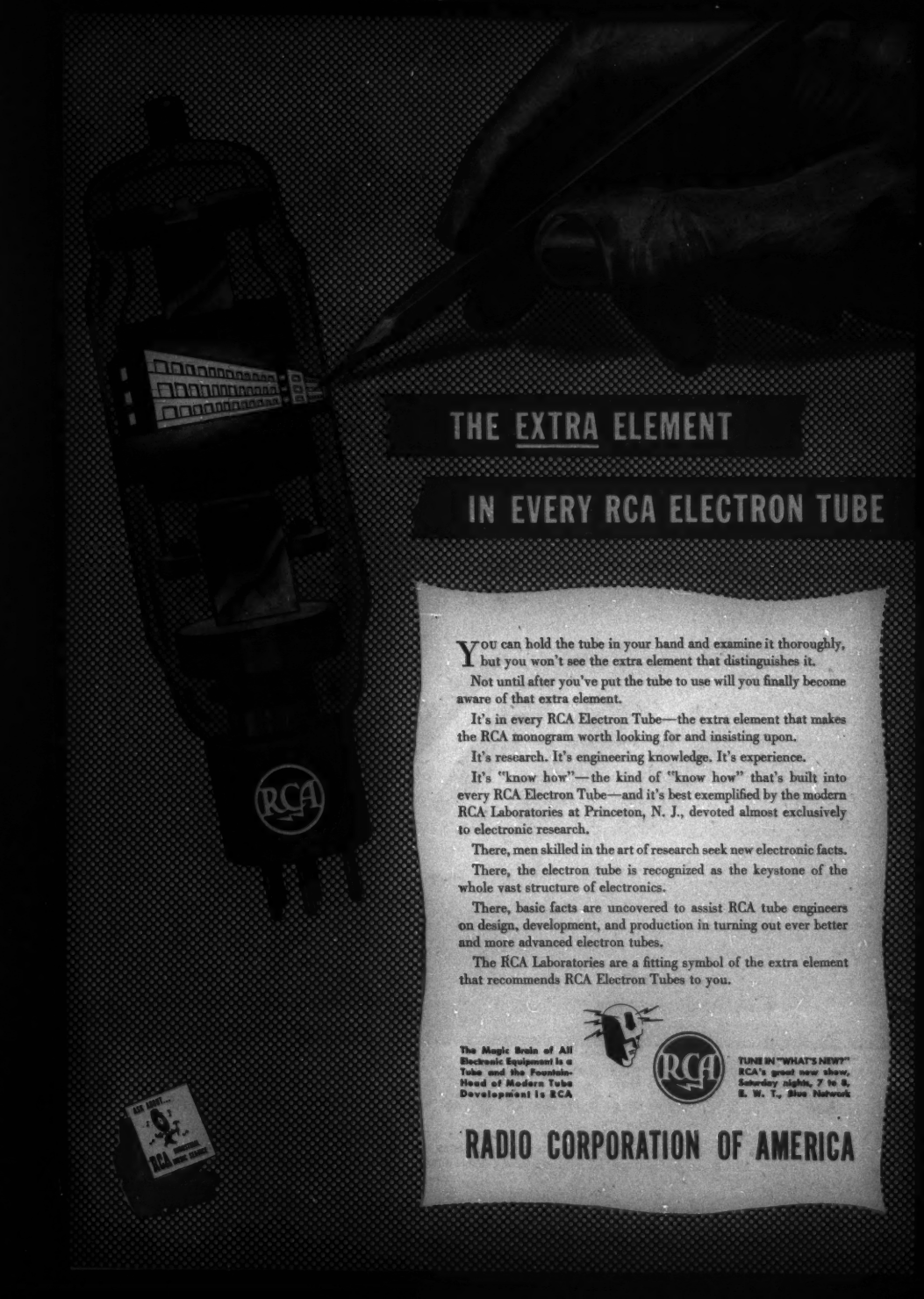
THE EXTRA ELEMENT
IN EVERY RCA ELECTRON TUBE
You can hold the tube in your hand and examine it thoroughly, but you won't see the extra element that distinguishes it.
Not until after you've put the tube to use will you finally become aware of that extra element.
It's in every RCA Electron Tube—the extra element that makes the RCA monogram worth looking for and insisting upon.
It's research. It's engineering knowledge. It's experience.
It's "know how"—the kind of "know how" that's built into every RCA Electron Tube—and it's best exemplified by the modern RCA Laboratories at Princeton, N. J., devoted almost exclusively to electronic research.
There, men skilled in the art of research seek new electronic facts.
There, the electron tube is recognized as the keystone of the whole vast structure of electronics.
There, basic facts are uncovered to assist RCA tube engineers on design, development, and production in turning out ever better and more advanced electron tubes.
The RCA Laboratories are a fitting symbol of the extra element that recommends RCA Electron Tubes to you.
The Magic Brain of All Electronic Equipment is a Tube and the Fountain-Head of Modern Tube Development is RCA
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RADIO CORPORATION OF AMERICA

A + B = C

AND SAVED THE CUSTOMER LOTS OF MONEY

"Of course we can make it," we told a customer after studying his latest blueprint of a coil form, "but we can save you a lot of money and give you more satisfactory service if you follow the suggestions of our Engineering staff. The boys recommend making the piece in two parts. They can be pressed quickly at a high production rate and assembled into a coil form of practically the same design as you brought us." Above are illustrated the parts which we finally shipped to the customer. Simple as A, B, C, isn't it?

But it demonstrates that it is well worthwhile to consider the services of American Lava when designing Steatite Ceramic Insulators. Perhaps we can make recommendations that will be of real benefit to you.

my-Navy "E"
st Awarded July 27, 1942
cond Award: "Star" February
13, 1943
rd Award: "Star" September
25, 1943

ARMY E NAVY

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STEATITE CERAMIC ELECTRICAL INSULATION
FOR ELECTRONIC USES

AMERICAN LAVA CORPORATION

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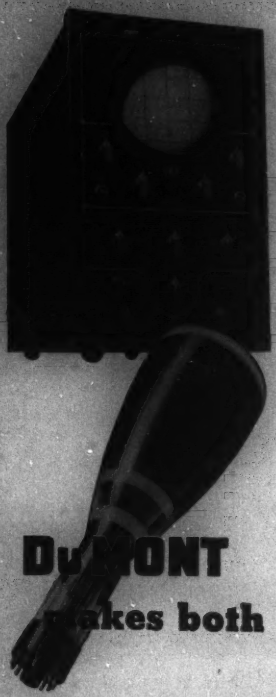

DuMONT
makes both

★ Yes, DuMont makes both—cathode-ray tubes and instruments. Pioneer of the commercialized cathode-ray art, DuMont has always insisted that such equipment be developed, designed and built as a thoroughly coordinated whole, since basically the equipment is but an extension of the cathode-ray tube itself.

That is why DuMont tube specialists and instrument-makers work side by side. Latest tube developments are immediately available to DuMont instrument-makers. Contrariwise, as DuMont instrument-makers evolve new circuits or functions, they can count on corresponding tube characteristics. Meanwhile, four DuMont plants translate that ideal coordination into up-to-the-minute tubes and instruments.

Always remember, DuMont makes both—tubes and equipment—for that complete, balanced, fully guaranteed instrumentation.

★ *Literature on request . . .*

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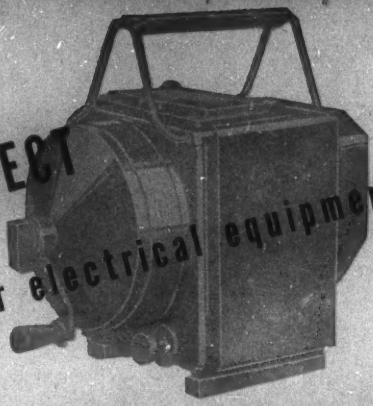

. . . use "MEGGER" Insulation Testing Instruments

These remarkable instruments should be used by every maintenance man who is seriously interested in forestalling electrical failures. They detect moisture, dirt and deterioration in the insulation of practically all types of electrical equipment. Having hand-cranked generators they require no batteries or adjustments and are wholly independent of external circuits. Ready for use anytime—anywhere.

If you are not aware of the protection afforded by the use of "Megger" instruments and their importance in keeping electrical equipment in operation, write today for the Pocket Manual of "Megger" Practice, No. 1420-EE.

THE NEW U. S.-MADE "MEGGER" INSULATION TESTER—Consists essentially of a direct-reading true ohmmeter of the permanent magnet moving coil type mounted with a d-c hand generator in a plastic molded case. Ranges up to 1000 megohms, with hand generators up to 500 volts. Widely used in hard service. Variable-pressure ("Meg") and constant-pressure ("Super-Meg") types. Bulletin 1735-EE.

THE "BRIDGE-MEG" RESISTANCE TESTER—This instrument is a combined "Megger" Insulation Tester and a four-dial, multi-ratio Wheatstone Bridge. Will measure any ohmic resistance from .01 ohm up to 100 or 200 megohms; hand generators rated up to 1000 volts. A complete and compact resistance measuring unit that is ideal for power companies and industrial plants. Catalog 1685-EE.

THE MIDGET "MEGGER" TESTER—In many ways the most remarkable "Megger" instrument ever built. Weighs only 3 lbs.—will fit an overcoat pocket or tool kit. Reads up to 50 megohms. Generates 500 volts and is always ready to use anywhere because of the hand crank. Send for Catalog 1685-EE.

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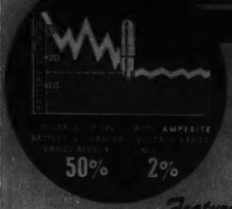

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1. Amperites cut battery voltage fluctuation from approximately 50% to 2%.
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Instruments and Automatic Controls

A large New England manufacturer is working on a broad post-war program of *pneumatic*, *electric*, and *electronic developments*, complementing well established lines of *aircraft* and *industrial instruments*.

The resulting products must go through a period of sales *pioneering* to achieve the degree of *customer acceptance* that will serve as a permanent basis for handling through our large sales organization.

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Vision: To see in today's unsolved problems of the industry, our products of tomorrow;

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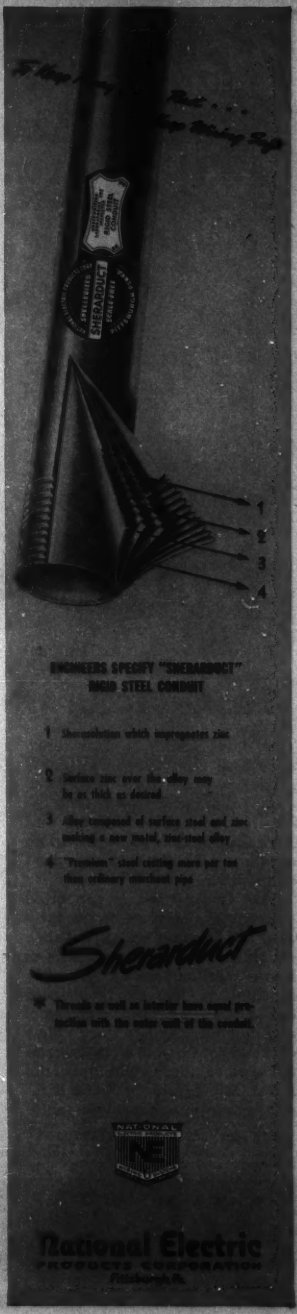

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(BOND TESTERS)

The modern way to test bond or contact resistance down to 0.0001 ohm.

Fast – Accurate – Easy to Use

The new Shallcross Low-Resistance Test Sets, Types 645 (Army range) and 653 (Navy range), include all of the features of the Shallcross Milliohmmeter and Aero Gun Models while providing greater portability, ease and speed of operation.

The Tester itself is supported conveniently in front of the operator by means of adjustable shoulder straps. Measurements as low as .0001 ohm are made, simply by attaching the fixed clamp to one side of the bonded surface, and touching the hardened points of the Pistol Grip Exploring Probe to the other side. The weight of the Pistol Grip Exploring Probe is reduced to a minimum by incorporating the meters, batteries, etc. in the suspended Tester cabinet.

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A sales engineer, specializing in *applications to industrial heating equipment, as ovens, dryers, furnaces,* is required to introduce the resulting new products to the market, establishing their correct application, and guiding our field representatives in absorbing them into their everyday practice.

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for a position with a future.

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Must be able to do market research and work in various industries to find need for new instruments.

Sales experience with engineering background required.

Apply to Box 319
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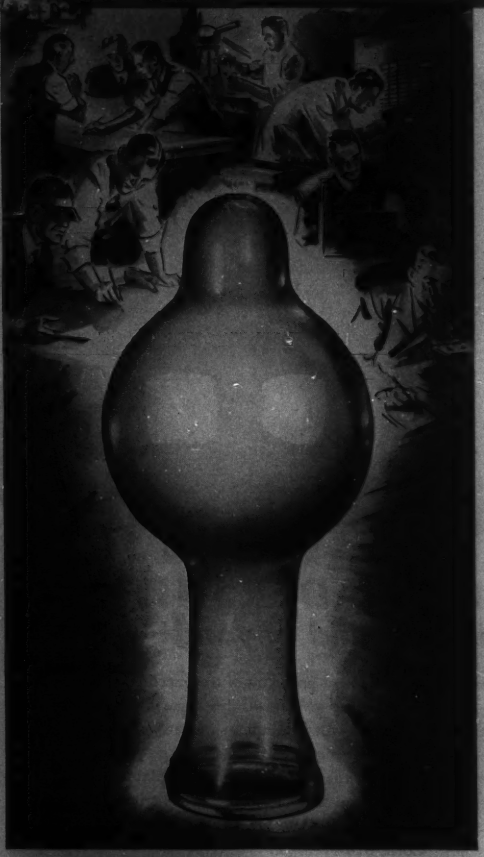

IT sounds like a big order—but we do it at Corning. And for any user of electronic glassware, big or little, this is a service mighty hard to equal.

Behind every radio tube, x-ray bulb, cathode ray bulb, resistor tube, every one of the hundreds of electronic glassware products made by Corning Glass—stand 250 glass experts. Planners, research workers, engineers, production men—each a specialist in his own right, backed by one of the largest, most modern laboratories in the United States.

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IN INDIVIDUAL METAL ENCLOSURES

00 to 10,000 Amperes
Up to 600 Volts A-C
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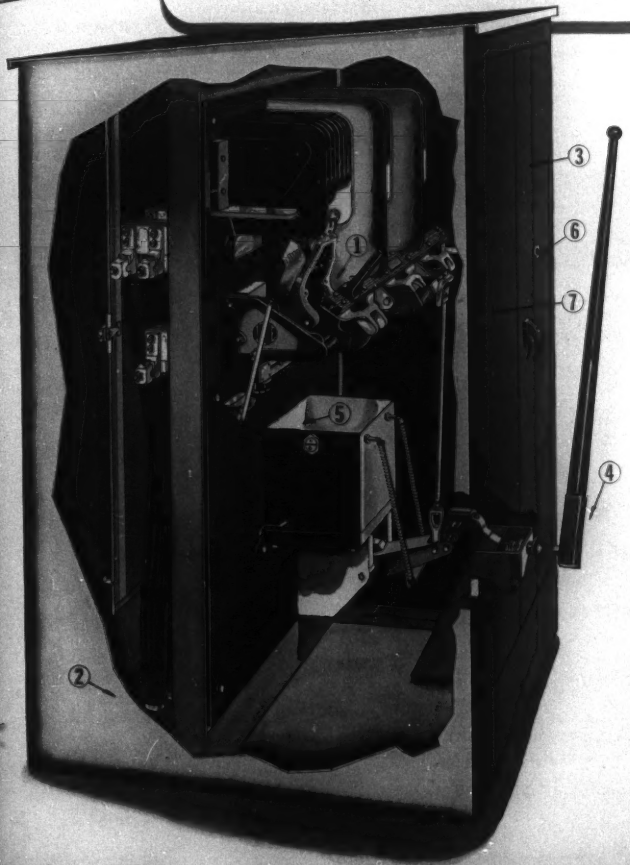
These large, enclosed I-T-E circuit breakers offer the same dependable service that thousands of U-Re-Lites, or medium-size enclosed breakers, have been giving for years. They are the time-tested type LG, mounted in individual steel cubicles for either indoor or outdoor service. They are easy to install and connect up, require very little maintenance.



(1) The type LG trip free circuit breaker is fully enclosed and protected to give reliable performance.

(2) Steel enclosure protects breaker against accidental damage and prevents men working nearby from touching live parts. The cables may enter at top, bottom or side. Outdoor enclosures are weatherproof, with a sloping roof and projecting eaves.

(3) Hinged doors are easily opened for inspection without removing breaker from service. Three-point latches assure tight closure. Similar rear doors make the connection studs fully accessible.

(4) Outdoor breakers use a removable, rotary, manual operating handle, as shown here. Indoor types may have either a rotary or spade handle.

(5) Solenoid operating mechanism with a trip-free relay is provided for electrically operated breakers. Control power may be d-c or a-c.

(6) Trip button is readily accessible without opening the doors. In outdoor types this button is covered with a flexible, weatherproof diaphragm.

(7) Position indicator may be seen through a small window, showing whether breaker is open or closed.

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AIR SWITCHGEAR

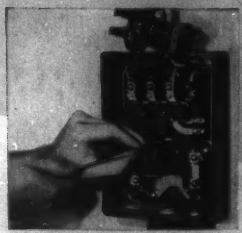
IMMERSED IN AIR • ENCASED IN STEEL

I-T-E

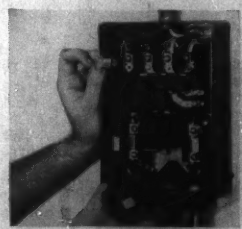
CIRCUIT BREAKER CO., PHILADELPHIA 30, PA.

Here's a Starter You Can Really Get At!

Loosen two screws and the arc chamber cover comes off. You can inspect every contact surface at a glance.



The entire armature and movable contact assembly can be lifted off after two more screws come out. You can easily slip off the magnet coil after disconnecting two wires from its screw type terminals.



Contacts are attached with separate screws—you can remove or replace them without disturbing any wiring—and a screw striver is all you need.

Peak operating efficiency and long life of electric motor starting equipment depend largely upon regular inspection and occasional servicing. Today, with every minute at a premium, this inspection and servicing job is more important than ever.

The complete accessibility of Square D starters means faster, easier inspection and servicing. Their simple construction enables the electrician to exchange magnet coils, contacts or overload relays in practically no time at all—using only a screw driver.

Write for Catalog Bulletin 8536 which describes Square D's complete line of A.C. magnetic starters. The starter illustrated is Size I for 3 phase motors up to 5 HP. at 220 volts or 7½ HP. at 440 volts. One smaller, and three larger sizes are also available.

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